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The Effectiveness of Mobile Eye-Tracking to Enhance Guided Show Cave Experiences

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THE EFFECTIVENESS OF MOBILE EYE-TRACKING TO ENHANCE GUIDED
SHOW CAVE EXPERIENCES

A Thesis
Presented to
The Faculty of the Department of Geography and Geology
Western Kentucky University
Bowling Green, Kentucky

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science

By
Jenna Hammond

August 2019

THE EFFECTIVENESS OF MOBILE EYE-TRACKING TO ENHANCE GUIDED
SHOW CAVE EXPERIENCES

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This thesis is dedicated to my late grandfather, Maxwell, who I can only imagine would be so proud. To my grandparents, Pam and Bernie, for their support and love. To my mother and sister, to whom I owe so much.

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Karst terrains are landscapes with a distinctive hydrology and set of landforms that arise from a combination of high bedrock solubility and well-developed secondary (fracture) porosity. Karst areas are easily polluted due to the rapid transport of unfiltered percolating water through the systems. While many individuals are able to identify karst landforms such as sinkholes and caves, an understanding of the interconnectedness of the surface and subsurface in karst landscapes, as well as the vulnerability of karst areas to degradation, is often limited. Show caves, which are caves made accessible to visitation by humans through built infrastructure, can serve as an excellent venue through which to educate large quantities of people about the importance of these landscapes and sensitivities of them to degradation. Using Carter Caves State Park as a case study site, this study revealed that mobile eye-tracking technology can be used to develop cave tours that are both educational and entertaining by identifying greatest visitor interest at stops and along tour routes (i.e., where a visitors' gaze falls throughout the tours).

Chapter 1: Introduction

Karst terrains are landscapes with a distinctive hydrology and set of landforms that arise from a combination of high bedrock solubility and well-developed fracture porosity (Ford and Williams 2007). These landscapes make up at least 12% of the ice-free land surface and are found on every continent aside from Antarctica (Veni et al. 2001). Karst landscapes supply 20-25% of the world's population with drinking water (Ford and Williams 2007). These environments are home to vast underground ecological systems, as well as other resources of paleontological, archeological, historical, and geological importance. Since karst landscapes allow for the rapid transport of poorly filtered percolating water and pollution throughout the terrains, karst areas are vulnerable to anthropogenic disturbance in the form of groundwater degradation, cave destruction, and biota habitat loss (Ford and Williams 2007). Many occurrences of anthropogenic disturbance are unintentional and most often occur due to a lack of understanding and/or exposure to karst science. In addition, globally, there is a lack of regulations designed to protect karst environments and insufficient monetary and time resources for land managers to properly oversee the protection of these landscapes (Fleury 2009).

Educating the general public about karst landscapes is frequently attempted on show cave tours, yet the content delivered to tour participants is often too abstract for the general public to fully understand (North 2011). Show caves are caves made accessible to visitation by humans through infrastructure such as trails, lights, and/or railings (Worboys et al. 1982). These caves are often available for visitation through guided tours, in which visitors are lead through the caves to designated stops where a guide delivers an interpretive talk. Frequently, the content delivered during guided tours focuses less on

karst environments and more on the history of the cave (North 2011). Yet, these tours create the perfect environment for the public to visualize the complexities of a karst system and, thus, could serve as an excellent venue through which large numbers of visitors can be educated about the importance of karst landscapes and the sensitivities of these terrains to degradation. By enhancing the environmental educational content provided during cave tours, the general public could be educated en masse on karst landscapes. Educating large groups about karst terrains could, in turn, contribute to a reduction in the occurrence of karst degradation by human activity since increased knowledge about a subject promotes more favorable human environmental behavior (Hungerford and Volk 1990).

Eye-tracking is a method of research through which a quantitative measurement of an individuals' points of interest and eye movements can be documented and quantified. Specifically, using specialized eye-tracking technology the region of interest (ROI) or fixations of an individual's eye, how long an observer views the ROI, and order of observed ROIs can be recorded and then correlated to understand processes that support cognitive development and behavioral activities (Duchowski 2007). By tracking the movement of a person's eyes during a show cave tour, the visual interest of visitors while at stops and walking along tour routes can be determined. This information can then be used to develop tours that have a greater focus on the common interests of visitors. The purpose of this research was to establish the ways in which karst education on show cave tours can be developed with the use of eye-tracking technology; specifically, by understanding what visitors are observing on tours, tours can be developed to deliver more precise information in targeted locations in an effort to create

tour experiences which are both educational and entertaining. The following research questions were answered through this research:

1. How can eye-tracking technology be utilized to improve the educational quality of guided show cave tours?
 - Can eye-tracking technology be used to identify common interest points along show cave tour routes?
 - If so, can identifying common points of interest on a cave tour enhance the understanding of the information provided to cave visitors?
2. How can information supplementary to guided tour content, such as ‘follow-along’ brochures, be created using eye-tracking data?

This research took place in two phases. The initial phase involved establishing the current educational value of the investigated show cave tours through pre- and post-assessments; this research methodology has proven effective for evaluating karst knowledge by North (2011). The second phase of this study began by quantitatively and definitively identifying gaze interest of cave tour participants using mobile eye-tracking technology; this was an important task to complete since the actual visual stimuli of cave visitors may differ from what show cave managers and guides assume are visual interests of tour participants. As part of this study, one participant on each of the tours in which pre- and post-assessments were collected wore a pair of Tobii Pro Glasses 2 eye-tracking glasses to help the researcher determine the cave features which visitors are most interested in while inside the cave. Data collected included gaze interest at and between regular tour stops. An additional component of the second phase of this study was developing tour content and identifying appropriate stops along the tour based on the collected eye-tracking and survey assessment data. Adapted tour experiences were evaluated with the same pre- and post-assessment instrument as used in the first phase of this study to determine whether the eye-tracking data-driven or original tour design was most effective at improving understanding of karst landscapes.

In summary, informing and educating the public on the importance of karst landscapes is crucial for the protection of these landscapes from human-induced degradation. Show cave tours are among the best ways to efficiently and effectively communicate about karst landscapes to an unknowing populace. Through the use of mobile eye-tracking technology, this study allows cave tour developers to better understand how tours can be developed in such a way to educate cave visitors, while also maintaining the entertainment value of guided cave tour experiences. The information revealed through this study helps to bridge the gap between common “entertaining” tours and educational resource interpretation.

Chapter 2: Literature Review

2.1 Karst Landscapes

A karst environment is described as a landscape underlain by carbonate rocks and filled with distinctive surface and subsurface features, such as caves, springs, and sinkholes that develop through the dissolution of soluble bedrock (White 1988; Ford and Williams 2007; Palmer 2007). Karst terrains make up at least 12% of the ice-free land surface throughout the world and are found on every continent except Antarctica (Veni et al. 2001). Karst landscapes supply 20-25% of the world's population with drinking water (Ford and Williams 2007). These terrains are home to vast underground ecological systems, with resources of paleontological, archeological, historical, and geological importance commonly present (Currens 2002; Ford and Williams 2007; Palmer 2007).

The formation of karst terrains is the product of five elements: rock type (geologic element), solvent (climatic element), fracture (structural element), gradient (topographic element), and time (historic element) (Groves 1993). Karst landscapes are typically formed within carbonate rocks, due to the distinctive sedimentary nature of the rocks (the high amount of open pore space) and the susceptibility of them to post-depositional alteration (Ford and Williams 2007). Limestone is the predominate carbonate rock in which karst landscapes form (Ford and Williams 2007). When water comes in contact with carbon dioxide, which may be found in soils (in decaying leaves or other biomass) and/or the atmosphere (where rainwater has a pH of 5.4), the two combine to form carbonic acid (H_2CO_3). This acidic water then seeps into the soil, interacting with the carbonate bedrock. The chemical reaction, $\text{CaCO}_3\text{-CO}_2\text{-H}_2\text{O}$, occurs, breaking the calcium carbonate compound into HCO_3^- and Ca^{2+} ions, which then initializes the

dissolution process (White 1988). The karst dissolution process ultimately creates a highly interconnected landscape between the surface and subsurface with complex hydrology. These landscapes consist of various features, such as sinkholes, sinking streams, springs, and caves that connect the surface and subsurface by providing pathways for the rapid transport of water from the surface to the aquifers below. This complex and hard to visualize hydrology makes karst landscapes difficult for the general public to understand (Tyrie 2014) and results in them often being ignored in most education settings (North 2011). Over time, a lack of public knowledge about karst landscapes can lead to increased degradation of karst resources and features; after all, if the public is not aware of the damage being done by their activities on the karst land surface, how can the behavior be corrected?

2.2 Threats to Karst

Since the presence of water is integral to the development of karst landscapes, human-induced environmental change in karst regions is reflected most by impacts to hydrologic processes (Ford and Williams 2007). Due to the interconnected nature of surface and subsurface features in karst terrains, any form of pollution that enters a karst system can have an influence on the entire system; the most common forms of pollutants in karst regions are fertilizers, pesticides, herbicides, sewage, accidental chemical spills or intentional dumping, and landfill leakage (Currens 2002; Palmer 2007). Modifying surface hydrology through the infilling of sinkholes, installation of drainage wells, deforestation, desertification, and mining can also degrade karst landscapes (Veni et al. 2001; Ford and Williams 2007; North et al. 2009). In short, the unique nature of karst hydrology, geology, and morphology make karst terrains vulnerable to pollution via the

concentrated movement of contaminants throughout the entire karst system and ultimately into the groundwater supplies contained therein (Parise and Pascali 2003).

Since karst landscapes provide significant amounts of water to the global population, karst groundwater contamination can have a severe impact on human well-being. Contaminated karst waters are frequently the result of degrading human activities (Ford and Williams 1989; Ulrich 1993; Drew 1996). For example, Palmer (2007) recounts how 2,000 people became ill from a contaminated karst aquifer in Ontario, Canada as a result of a pathogenic bacteria outbreak.

Sinkholes are a prominent feature of many karst landscapes and are one of more recognized karst features. Due to the nature of sinkholes, they can also be one of the easiest ways humans can degrade a karst environment (Metcalf and Hall 1984; van Beynen and Townsend 2005; Gutiérrez et al. 2014); logging, leaking pipes, concentrated stormwater and agricultural runoff, irrigation, and increased urbanization are all anthropogenic influences that can lead to sinkhole development. These features frequently serve as drainage points for contaminated stormwater or are used as illegal dumps (Crawford 1984; White et al. 1984). The clogging of sinkholes with debris or garbage can create flooding hazards for karst communities (Crawford and Veni 1986; Parise and Bonacci 2010). Urban development on top of karst landscapes can also lead to the degradation of the aquifer since creating larger areas of impermeable surfaces limits groundwater recharge to the aquifer, resulting in further sinkhole development and increased instances of stormwater pollution or flooding (Gutiérrez et al. 2014).

Lack of education is perhaps the largest threat to karst terrains since ignorance of karst systems can directly result in multiple other threats. Kastning and Kastning (1999)

outline nine common misconceptions of karst terrains that come about through misunderstanding of karst areas by of the policymakers and general populace living in these regions. The misconceptions outlined by Kastning and Kastning (1999) include: 1) karst bedrock is solid; 2) water enters, not creates, sinkholes; 3) pollutants placed into the ground remain there; 4) karst spring water is pure; 5) sinkholes only form catastrophically; 6) karst is always exposed at the land surface; 7) erosion forms caves; 8) caves and the rocks they are formed in are the same age; and 9) karst groundwater flow is simple. North (2011) suggests that scientific data regarding karst is abundant, but distributed poorly throughout society, thus creating or enhancing these misconceptions. As an example, Fleury (2009, 46) found that 48% of participants connected to municipality departments (local governments handling water systems, specifically) identified the “most serious karst-related problem” as groundwater contamination, while 63% suggested that cave protection is the “least important”, despite the two concepts being directly related. In order for complex karst systems to be properly managed and protected, it is imperative that the people living on, and interacting with, karst landscapes understand the interconnected nature and dynamics of karst systems, as well as the influence of human activities on the health of karst environments. Yet, as reported by North (2011), karst education efforts globally are lacking or are ineffective in their content design and delivery.

2.3 Environmental Education

Stapp (1969) put forth that the main, foundational goals of environmental education are to make citizens more knowledgeable about the biophysical environment and the problems therein, determine strategies to help solve problems, and provide

motivation towards solutions to problems. Roth (1970) described environmental education as instilling knowledge about biophysical and sociocultural environments and fostering awareness of management alternatives for environmental problems. These foundational works on environmental education were followed by a plethora of other environmental education developments throughout the 1970s with the Tbilisi Declaration (UNESCO, 1978). The Tbilisi Declaration established the following goals as a basis of environmental education: 1) to foster a clear awareness of, and concern about, economic, social, political and ecological interdependence in urban and rural areas; 2) to provide every person with opportunities to acquire the knowledge, values, attitudes, commitment and skills needed to protect and improve the environment; and 3) to create new patterns of behavior of individuals, groups, and society as a whole towards the environment (UNESCO, 1978). This environmental education movement extended into the 1990s with the adoption of the National Environmental Education Act and the creation of the Office of Environmental Education within the U.S. Federal Government. Roth's (1970) definition can be extended in the present-day to reflect the movement of science curriculum developers, such as the National Academy of Sciences, to create conceptual frameworks that encourage integration between different scientific disciplines (National Research Council 2012).

Despite an increased demand for environmental education, there has been little research on the topic of adults learning through informal education experiences; instead, education research has largely focused on youth learning through formal education (Gough et al. 2001) or adults who participated in programs as children to understand the lasting impact (Williams and Chawla 2016). Yet, according to North (2011, 35), "the

average person only spends approximately three percent of his or her lifetime in school...merely a small percent of a person's knowledge is actually obtained in formal education settings." Formal education is a method of learning that requires a teacher in a position of authority to establish rules and requirements that ensure students acquire knowledge and learn effectively from a pre-established standard (Hein 1998; Bekerman et al. 2006). Similarly, nonformal learning is learning through an organized activity, such as a visit with a class to a museum or science center; these activities may be overseen by either licensed or non-licensed instructors outside of the standard classroom environment but are directly associated with formal education (Coombes 1973; La Belle 1982). Formal learning environments follow a predefined curriculum; effectively, formal education is a method of 'forcing' learning on students. For example, La Belle (1982, 163) defines formal learning characteristics as, "hierarchical ordering, compulsory attendance, admissions requirements, standardized curricula, prerequisites, and certificates", as opposed to informal education which is characterized as "the contact individuals have with a variety of environmental influences that result in day-to-day learning." The initial guiding principles of environmental education were designed to have active participation (Weilbacher 1993); this relates to further research on environmental education. Published research on environmental education references the notion that environmental education is most effective when learning takes place in the physical environment being studied (Stapp 1969; Hungerford and Volk 1990; Falk 2005), as this creates a connection between the student and the environment and, thus, a more meaningful learning experience.

2.3.1 Informal Education

Informal learning is a supplement to both formal and nonformal learning, and promotes real-world, lifelong learning. The National Research Council (2012), Griffin (1998), and Falk and Dierking (2000) definitions can be combined to describe informal education experiences as learner-motivated, driven by learner interests, voluntary, personal, ongoing, contextually relevant, collaborative, nonlinear, and open-ended. While environmental education can occur throughout all three methods of learning, informal learning, in some regards, most closely aligns with the modern concept of environmental education in that a student must feel connected to the environment in order to respect it (Frantz and Mayer 2014). While formal education takes place primarily in schools and other institutions by licensed instructors, informal education can happen spontaneously, in an incidental situation without an instructor or mentor (Hein 1998; Bekerman et al. 2006), with nonformal education having an instructor such as a park guide or interpreter. North (2011) suggests that, instead of licensed instructors, nonformal and informal educators can be tour or museum guides, camp counselors, troop leaders, and so on, in various locations, such as parks, zoos, museums, or even show caves.

Informal science education is often a one-time learning experience, and material is presented using a single medium such as a museum exhibit or interactive display (Bitgood 1988; Field and Powell 2001). Due to the limited interactions between informal educators and learners, the material discussed through informal learning experiences tends to be broader and aims to “encourage change in learning about the environment, to improve levels of interest, and to increase the learner’s knowledge through contextual cues from the outside world” (Kola-Olusanya 2005, 298). This provides unique benefits

to informal learning students; specifically, informal and nonformal education encourages learning without assessments. Payne (2006) revealed that formal classroom learners are often only focused on the progression of knowledge. Heimlich (1993) added that these formal audiences are often only motivated to learn by the grades they will receive and not through interest in the subjects.

The benefits of informal and nonformal education are well-documented. For example, Ballantyne and Packer (2005) indicated that nature-based tourists who enjoy their experience may be more open to becoming involved in adopting a pro-environment behavior, thereby creating favorable behavior changes. Researchers have also suggested that people who learn in informal settings are more likely to retain the information presented to them (Falk and Dierking 2000). Informal education can also fill gaps in a person's education or regularly update their knowledge (Falk and Dierking 2000; North 2011). Brodie (2001) found that a wider range and a larger number of people can be impacted through informal learning when compared to traditional formal educational settings. Nature-based tourist locations provide visitors with appropriate informal education and recreational opportunities simultaneously (Brodie 2001). Yet, despite the many documented benefits of learning through informal settings, informal education has largely been neglected by scientists and education practitioners when compared to the amount of research completed with regard to formal education; additionally, the majority of karst education research, specifically, has concentrated solely on formal learning (North 2011). This research focused solely on informal karst education provided through show cave experiences.

2.3.2 Environmental Interpretation

A method of nonformal education used heavily within the National Park Service (Tilden 1977; Sharpe 1982; Ham and Krumpe 1996) and other nature-based tourism experiences, as well as in many other informal learning setting (Cardea 1999), is environmental interpretation. Tilden (1977, 8), defines interpretation as “an educational activity which aims to reveal meaning and relationships through the use of original objects, by first hand experiences, and by illustrative media, rather than simply to communicate factual information.” Ballantyne and Uzzell (1994) expanded upon the definition of interpretation to note that it can be utilized to educate visitors of all ages through stories about the locations being visited in an engaging, interesting, and enjoyable way in an effort to change a person’s environmental knowledge, skills, attitudes or values, and behavior. Table 2.1 outlines the main differences between formal environmental education and nonformal environmental education.

Table 2.1. Differences between typical environmental education; formal and nonformal. Adapted from North (2011, 53).

	Formal Environmental Education about the environment	Nonformal Environmental Education
Who?	School teachers, education officers, teacher educators	Interpreters; exhibition designers, rangers, interpretative trainers
What?	Understanding of environmental concepts and acquisition of environmental skills	Information about people, places and objects, interpretation of meaning
To whom?	School children, adult continuing education	Tourists, residents, wide age range
Why?	Develop environmental literacy, fulfill curriculum objectives	Recreation, entertainment, site conservation, profit
Where?	Schools, field study	Interpretive centers, parks, museums
When?	School trips, in-class lessons for preparation or follow-up trips	Engaging in recreational or tourism activity with limited time involvement

Tilden's (1977, 9) principles of interpretation, which are still being used to guide interpreters today, are defined as:

1. Any interpretation that does not somehow relate what is being displayed or described to something within the personality of experience of the visitor will be sterile.
2. Information, as such, is not Interpretation. Interpretation is revelation based upon information. But they are entirely different things. However, all interpretation includes information.
3. Interpretation is an art, which combines many arts, whether the material presented are scientific, historical, or architectural. Any art is in some degree teachable.
4. The chief aim of interpretation is not instruction, but provocation.
5. Interpretation should aim to present a whole rather than a part and must address the whole man rather than any phase.
6. Interpretation addressed to children should not be a dilution of the presentation to adults, but should follow a fundamentally different approach. To be at its best will require a separate program.

While national parks, or other similar locations, are among the most cited use of interpretation (Oliver et al. 1985; Manfredo 1992; Kohl 2005), there is little research done on nonformal learning and interpretation in a park setting (North 2011). A study by Brody and Tomkiewicz (2002) was conducted at Yellowstone National Park to determine how visitors' understanding, values, and beliefs were affected by visits to the park. The study found that visitor learning was influenced through understanding of prior geological concepts, discussions of interpretive signs and park experiences, and their personal desire to learn because of the unique landscape (Brody and Tomkiewicz 2002). These findings mostly align with the Model of Free-Choice Learning (Falk 2005), studied further by Bamberger and Tal (2007), which indicates that visitors must be self-motivated and have some prior background knowledge about a subject in order to learn effectively new material about the topic.

Interpretive tours, regardless of topic, can be biased toward entertainment or education. This bias towards either entertainment or education can often isolate a portion of the tour group, as many visitors prefer one to the other; yet, Ansbacher (1998) emphasized that entertainment and education are not mutually exclusive. Despite research on how show cave interpretation can become more educational by North (2011), and how cave guides can be trained to present educational material in a more effective manner (North and van Beynen 2016), there is still a need to better understand how show cave interpretative experiences should be developed to maximize both education and entertainment. The ideal show cave tour should provide adequate information for visitors to understand a complex, interconnected karst system, while also retaining an entertainment value to keep visitors engaged. The question remains, however, “what is the best way to achieve this goal?”.

Many entities that actively use environmental interpretation as an education technique (National Parks, botanical gardens, wildlife refuges, etc.) are forms of ecotourism (North 2011). This is described as a form of tourism that emphasizes visitation to natural areas and/or wildlife (World Tourism Organization 2001). Ecotourism is often considered a “win-win” in which tourists are able to experience enjoyable trips, while also generally learning about the natural world and conservation (Honey 2008). According to Honey (2008), nature-based tourism, or ecotourism, is expected to grow by at least 15% annually throughout the global tourism market for the foreseeable future. Bricker et al. (2013) indicated that there is a dramatic increase in demand for ecotourism throughout the world.

2.3.3 Learning Theory and Design in Interpretation

Conceptual Change Theory, as studied by Posner et al. (1982) and Magnusson et al. (1997), suggests that, if possible, educational material should be presented in such a way that meaningful linkages can be made between new, difficult concepts and existing knowledge. This suggests that visitors to show caves could be informed of common misconceptions in cave and karst science and provided with an alternate perceptions of the karst landscapes. Falk (2005, 275) describes the Model of Free-Choice Learning as, “Free choice learning is relative, rather than an absolute, construct. The operative issue is perceived choice and control by the learner. To qualify as free choice learning, the learner must perceive that there are reasonable and desirable learning choices (as defined by the learner) available, and that s/he possesses the freedom to select (or not to select) from amongst those choices...”. Since show cave visitors are self-motivated to visit the cave and are likely to be presented with information that is previously unknown or misunderstood (North 2011), the interpretative strategies presented in both the Model of Free-Choice Learning and Conceptual Change Theory can be directly applied to this study. Considerations must be made as to how information is presented, what motivates visitors to participate and their expectations of a tour experience, and what are the previous experiences with karst landscapes of visitors, as these items all influence how visitors learn (Brody and Tomkiewicz 2002; Bamberger and Tal 2007).

In an ideal world, visitors to a cave would be able to freely explore and learn as they go, as in a museum setting, yet due to the safety issues present within the cave environment, guided tours are among the only reasonable way to see many of them. The goal of this research was to create a show cave tour that meets the prerequisites for

museum learning from Bosivert and Slez (1994) and follows the suggestions of exhibit design presented in Botelho and Morais (2006). Bosivert and Slez (1994) suggested that there are three prerequisites for museum learning: attraction by drawing a subject's attention, holding power by maintaining attraction, and engagement by soliciting the subject to interact with the exhibit. Botelho and Morais (2006) explored the characteristics that affect student learning in interactive exhibits at science centers; this study found that in order to maintain students interest, the exhibits must be designed in such a way which clearly presents the concepts to be learned and be as interactive as possible. Similarly, Kastning and Kastning (1999) believe that for visitors learning about karst terrains for the first-time, information should be presented through maps, photographs, drawings, and/or other visual devices. Show cave tours are led traditionally by guides who have varying background knowledge of karst, presenting a set version of a tour with specific constraints (North and van Beynen 2016). Due to these factors, there is often not a chance for tour guides to provide the types of information suggested by Kastning and Kastning (1999) during a guide cave tour experience. By utilizing past research on exhibit designs, learning in nonformal settings, and first-time karst terrain learners, the current project may allow for the creation of an effective, nonformal educational experience relating to karst terrains.

2.4 Eye-tracking

Eye-tracking is a method of study that analyzes the movement of a person's eyes to understand the common influences of attention and comprehension (Tanehaus and Spivey-Knowlton 1996). Duchowski (2007) outlines the many uses of eye-tracking technology, primarily those in the fields of neuroscience, psychology, marketing and

advertising, and computer science, since eye-tracking is especially useful in studies related to information processing. Eye-tracking focuses on the occurrence of saccades, rapid eye movements occurring at intervals of 10 to 100 milliseconds (Duchowski 2007), and fixations, the amount of time eyes focus at one point; these factors are believed to be an indicator of perceptual processing (Mayer 2010). An observers' attention can also be described as a function of two actions: foveal (fixations) and parafoveal (where the observer looks next) (Duchowski 2007). By establishing an observers' visual path when presented with information, researchers can establish specific regions of interests that support cognitive and behavioral activity for the observer.

Since eye-tracking has been utilized to study how people learn from videos and static images (in stationary eye-tracking), many researchers suggest that mobile eye-tracking (MET) may be beneficial to determine how people can learn about a specific location while physically moving throughout it (Evans et al. 2012, Tyrie 2014). Gordin and Pea (1995) suggested that viewing scientific visualizations can make science learning more accessible. Libarkin and Brick (2002), however, found that while there is potential for great understanding from static visualizations, many students in an educational setting do not understand how to interpret and use visualizations; this research could imply that by having an interactive approach and guiding learners to the information determined as most important to learning, learners will more effectively learn presented material.

While research on eye-tracking has advanced steadily since the 1970s, there are few instances of eye-tracking technology being used in any geologic environment. Eye-tracking has rarely been used to examine learning about a karst system, even in a stationary eye-tracking setting. A geoscience eye-tracking study by Griffin and Robinson

(2010) used eye-tracking techniques to better understand the use of visual stimuli to highlight key features of the environment, such as color and leader lines, and found that both methods were equally effective. Evans et al. (2012) used MET in an outdoor setting to assess the learning of professional and novice geologists by focusing on the variations in eye movements between the two populations; the researchers discovered that the professionals focused for less time on various sites during the study, while the novice spent more time focusing and shifting their gaze, likely in an attempt to understand the scene without additional help. This information is useful to this research in that the novice geology student would likely mimic how a first-time visitor would react in a show cave setting. Tyrie (2014) further suggested that using eye-tracking on a show cave tour could be beneficial to the understanding of karst systems after the researcher discovered that static motion, 3D models of karst systems with smart labels/descriptive text were the most effective visualizations for learning about karst landscapes. Thus, utilizing MET in the cave environment offered researchers an opportunity to identify areas of effective visualization for cave visitors, and by providing supplemental information, the visitors had the best possible chance at understanding the environment.

2.5 Summary

In conclusion, very few studies have explored the role of nonformal environmental education in the protection and conservation of karst landscapes, yet other research in nonformal environmental education suggests that it is a critical tool in the preservation of fragile environments. Even fewer studies have explored the use of mobile eye-tracking technology in any type of outdoor learning environment; there has not been a single study in which mobile eye-tracking has been used inside of a cave. The literature

reviewed as part of this study suggests that eye-tracking can be a powerful scientific tool to study how people can learn in stationary and mobile settings. One such study found that stationary eye-tracking for karst education is a very effective method to develop more precise karst diagrams (Tyrie 2014); the same study suggested that using mobile eye-tracking technology to develop cave tours can have a positive influence on the development of current and future show cave tours that are both educational and entertaining. Currently, many show caves have tours that poorly disseminate educational material; difficulties in the delivery of educational content are further complicated by the use of poorly trained guides or logistical difficulties managing large tour groups through the cave environment. This research project provides insight into the improvement of delivered content and methods of improving the navigation logistics of the tours themselves, with the ultimate goal of educating en masse about karst landscapes, thereby reducing instances of human-induced degradation of karst areas.

Chapter 3: Study Area

This study took place at a show cave with limited amounts of educational resources available to visitors. The study site, Carter Caves State Resort Park, was chosen in Kentucky due to the abundance of karst terrain and the lack of standardized education material about karst landscapes across the state. Carter Caves State Resort Park is operated by the state government. This study site was chosen due to the high rates of visitation and location in an area of high concentration of karst terrain. The site has very limited resources to provide visitors with additional information relating to karst landscapes, unlike other sites in Kentucky (such as Mammoth Cave, Hidden River Cave, or Lost River Cave). The area is geologically similar to the Mammoth Cave area, one of the most studied karst regions in the world. The area is capped by Pennsylvanian sandstone and conglomerates with Mississippian carbonates, in which the caves are developed (Lierman et al. 2011). Limited research exists about the environmental risks associated with the study area, but the presence of karst terrain suggests environmental risks to public health near the study sites. Specifically, Carter Caves is located near a small urbanized (less than 5 miles from two cities with populations of 5,000) area with many agricultural locations in the immediate watershed; groundwater contamination from animal waste, agriculture, urban stormwater runoff, and underground storage tanks is likely prevalent due to the abundance of shallow aquifers in the area (May et al. 2005). Other such issues include exacerbated sinkhole flooding from urbanization and modified surface drainage causing further collapses in sinkholes (Gutiérrez et al. 2014).

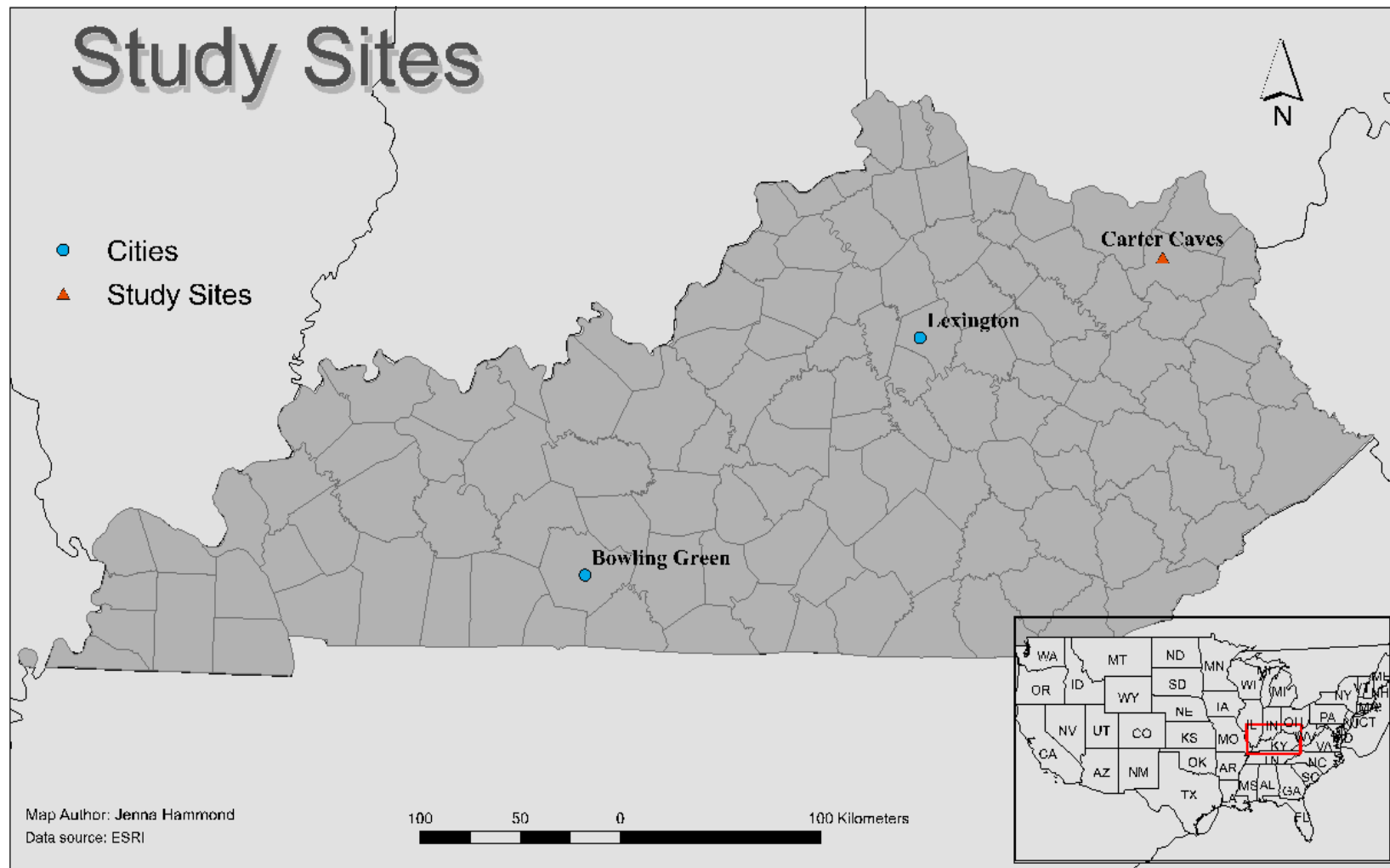


Figure 3.1. Map of Kentucky with location of Carter Caves State Resort Park. Created by author.

Carter Caves State Resort Park, located in north-eastern Kentucky approximately 150 kilometers east of Lexington, has approximately 100,000 visitors a year participating in guided cave tours (Ainsley, personal communication, 2017). The park lies on the western edge of the Cumberland Plateau with many stream-eroded hills and ridges and narrow valleys present in the park. Geologic features of the area include numerous caves, sinkholes, natural bridges, gorges, waterfalls, box canyons, and rock houses (Lierman et al. 2011). The local population is very familiar with the caves in the area, in that the caves have been a popular destination by the locals for many years. The area was previously a collection of private show caves until it became a state park in 1946; additional land was obtained for Carter Caves State Resort Park as recently as 1981. Carter Caves State Resort Park covers around 2,000 acres; the site is also designated as Bat Cave and Cascade Caverns State Nature Preserve, which was established for the protection of not only the expansive cave system, but also of the Indiana Bat and two trees: Mountain Maple and Canadian Yew (Lierman et al. 2011).

The county where the cave is located has a total of nearly 200 known caves and numerous sinkholes, many of which are used as dumping sites. Many local residents depend on karst spring water for their drinking water supply, thus there is a high priority for education in this community (Ainsley, personal communication, 2017); yet, with no museum or exhibits, Carter Caves State Resort Park has few resources through which visitors can learn about karst and caves other than through guided cave tours. Park guides occasionally are present to address questions from park visitors. Slim informational brochures describing the four caves tours also available for park visitors at the visitor center.

While there are several cave tours available for visitors at this location, for the purposes of this research only Cascade Cave was studied. Cascade Cave, the longest show cave on the park property, covers approximately $\frac{3}{4}$ of a mile and is explored through a 75-minute tour. This tour typically has at least 4 interpretive stops which showcase the bedding-controlled passages, large open chambers, flowing waters, and a large array of speleothems. This tour typically focuses on all aspects of the park, particularly on its history and geology; however, the lead guide determines what specific content will be delivered. Visitors are often encouraged to ask questions throughout the duration of tours. A maximum capacity of 120 visitors can view the cave at one time, children under 6 excluded from the count. The average number of participants on this tour is around 60 (Ainsley, personal communication, 2017).

While the aforementioned tour at Carter Caves State Resort Park have identified objectives for content to be delivered at specific stops, guides will generally determine the information provided throughout their tours. According to the park naturalist at Carter Caves, guides are not required to have a specific background in geology, education, or the like, and often train one another (Ainsley, personal communication, 2017). Those who have been an active guide longest, generally have the final say in what is taught to the new guides. The new guides will then, hopefully, conduct research on their own to further develop their tour script (Ainsley, personal communication, 2017).

Chapter 4: Methodology

To achieve the goals of this study, a mixed-methods approach utilizing mobile eye-tracking, pre- and post-assessments, and semi-structured interviews was employed. These methods were used to help understand how best to enhance the karst education content provided on show cave tours by analyzing the gaze patterns of cave visitors, assessing visitor learning outcomes, and determining trends in visitor experience. This research took place in two phases. The study initial phase involved establishing the current educational value and visitor experiences of the investigated show cave tours through pre- and post-assessments, as well as collecting eye-tracking data and conducting semi-structured interviews with tour participants on unaltered tours (Figure 4.1). The second phase of this study involved revising the design of existing show cave tour content and/or stops at each study site based upon these collected eye-tracking and outcomes assessment data. Two types of modified visitor experiences were created during this phase of the study. The first modified experience (Figure 4.2) consisted of no changes in the spoken content of the tour; instead, participants were provided with supplemental karst information via a brochure/pamphlet. The second modified experience (Figure 4.3) is a modified version of the pre-existing tour, with a change in the content delivered to reflect the educational needs as gathered from the assessments, as well as changes to trial stops to align with locations of greatest visitor interest based on eye-tracking data.

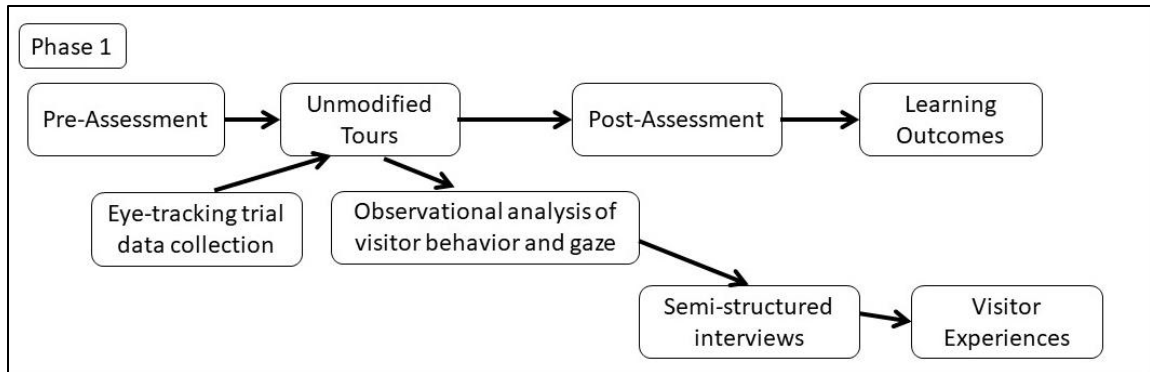


Figure 4.1. Flow chart of data collection and analysis for phase 1. Created by author.

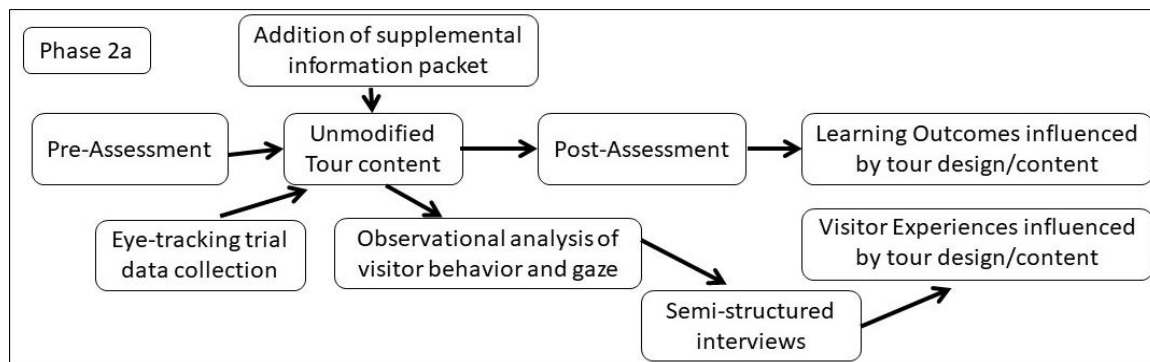


Figure 4.2. Flow chart of data collection and analysis for phase 2a. Created by author.

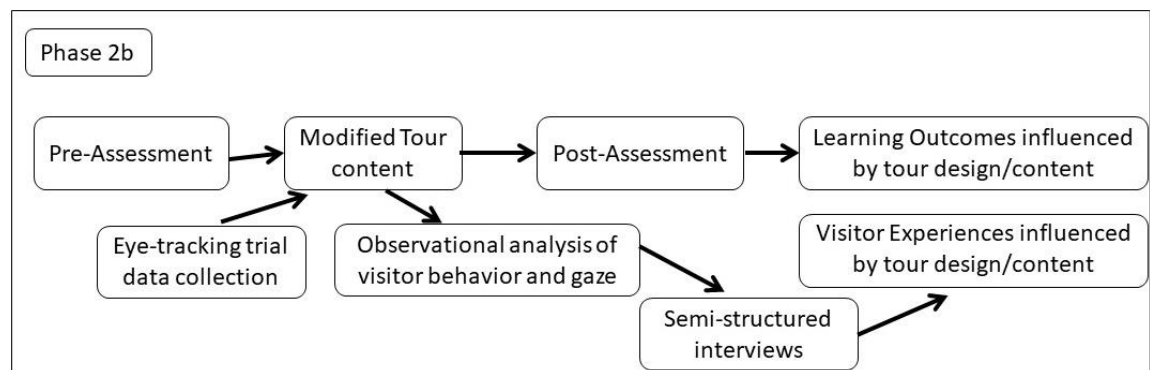


Figure 4.3. Flow chart of data collection and analysis for phase 2b. Created by author.

4.1 Participant Recruitment

Adults aged 18 or older were recruited for data collection through a voluntary sample design; pre-screening participants was not possible. Two varieties of participants were recruited: 1) visitors who only wore the eye-tracking glasses and participated in a semi-structured interview and post-assessment, and 2) visitors who only took a pre- and post-assessment. Both participant groups were on the same tour, but were unrelated individuals not traveling in the same group to eliminate potential bias of the eye-tracking participants seeing the assessment instrument. Participant recruitment for Carter Caves State Resort Park took place both at the visitor center and at the cave entrance. The park promoted the research on their social media accounts to encourage more participants to visit the park, as the visitation numbers for this year were down “significantly” according to the park naturalist. All data collection followed procedures approved by the Western Kentucky University Institutional Review Board and were conducted under a permit provided from Kentucky State Parks.

Participants for the pre- and post-assessment were approached as they arrived at the tour location; visitors who were aged 18+ and traveling alone or with a partner were approached first until at least two participants were recruited for each tour. Assessment participants were approached no later than 10 minutes prior to any tour departure time in order to allow enough time to complete the assessment and cover any necessary information prior to the start of tours. For data analysis, assessment participants were labeled according to the phase of study and number of the participant; for example, P1.2 would be participant 2 of Phase 1.

Prospective eye-tracking participants were approached a minimum of 30 minutes prior to the cave tour departure time. Visitors who appeared to be able-bodied and in good health, travelling alone or with a partner were approached first so as to ensure the participant would not have difficulty navigating the tour and to limit the potential distraction of an adult participant being preoccupied by looking after children, talking to acquaintances, etc. There were instances in which visitors who traveled with older children (around 16 years old) were recruited for eye-tracking when no other participants were willing or able. Recruitment took place at the cave entrance study site, and upon successful recruitment of eye-tracking participants, the eye-tracking glasses were calibrated in a small former ticket stand at the cave entrance to more closely mimic the cave environment. For data analysis, eye-tracking participants were labeled according to the phase of study and number of participant; for example, EP1.2 would be eye-tracking participant 2 of Phase 1.

In total, 90 pre- and post-assessments and 27 eye-tracking/semi-structured interview participants participated in this study. While 30 eye-tracking participants was the goal, due to technological difficulties with the eye-tracking glasses, a full set of 10 eye-tracking participants was not achieved during the final phase of this study. As previously mentioned, volunteers who used the eye-tracker did not participate in the pre-assessment portion of this study as to not bias their natural behavior during their guided tour.

4.2 Pre- and Post-Assessments

Once a participant was recruited, he or she was asked to review the Western Kentucky University Institutional Review Board stamped, approved informed consent

document for the study. He or she was then given a pre-assessment to complete prior to departing on the cave tour. Assessment data was used to determine in what ways gaps in the cave tours' educational content and/or identify tour content that was not fully understood by tour participants. Questions were based upon the previously discussed misconceptions related to karst environments (see Chapter 2). Questions, shown in Appendix A, included "Define or describe a karst landscape" and "In what ways do human actions impact karst terrains". Assessment questions were constructed so as not to be misleading or guiding in anyway, and were validated for question understandability and for ideal answers by peers within the Western Kentucky University Department of Geography and Geology, as well as former Mammoth Cave National Park guides; these individuals gave their responses and offered ways to improve wording and clarity of questions. The initial questions were found to be effective in a study conducted by North (2011), with new questions being added at the study site's discretion. The potential to add local questions concerning to the history of the park and cave was discussed with staff, but it was decided not to add any additional questions due to the difficulties with training staff on the history. According to the park naturalist, there are few written documents relating to the history of the cave and given difficulties with training (due to budget constraints), it would be easier to not require history on cave tours.

A series of demographic questions were included at the end of the post-assessment. The placement of the demographic questions at the end of the post-assessment was in an attempt to eliminate non-response due to fear of identification (Teclaw et al. 2012). Asking demographic questions last can also help ease the concern that the study is about the participant's individual performance (Leech 2002). The

complete assessment generally took less than ten minutes to complete. The full assessment instrument, adapted from karst education studies by North (2011) and Tyrie (2014), is shown in Appendix A.

In order to accurately reflect the characteristics of the show cave facility, no more than ten assessments were distributed per tour, this would allow for more results with the varying guides, with varying tour logistics and demographics. Assessments were distributed on tours with varying guides, as each guide gave slightly varied information. A total of five individual guides were used for this study. Upon completion of the cave tour, each participant completed a post-assessment consisting of identical questions as those included on the pre-assessment to assess what karst knowledge was learned during the cave tour. This research design was proven effective for evaluating karst knowledge in North (2011). Throughout the study a total of 90 pre- and post-assessments were collected. These assessments were used to help create the new “modified” tour for the later part of this research.

4.3 Mobile Eye-tracking Trials

Quantitatively and definitively identifying gaze interest of tour participants was crucial to this study, as the actual visual stimuli of cave visitors may differ from what show cave managers and guides assume are visual interests of tour participants. Thus, one participant on each of the tours in which pre- and post-assessments were distributed were outfitted with a pair of Tobii Pro Glasses 2 mobile eye-tracking glasses to help researchers determine the cave features that visitors are most interested in while inside the cave; the eye-tracking trials occurred independently of the pre- and post-assessments. The eye-tracking glasses utilized in this study (Figure 4.4) consist of a compact glasses

frame, equipped with four infrared eye cameras capable of tracking pupil and gaze patterns, and an attached recording unit (Tobii 2016). Data collected by the glasses included gaze interest at and between regular tour stops. In addition to the eye-tracking glasses, a tablet with Windows 8 or later software was used to operate the glasses. SD cards were used to record the individual trials, with all data backed up on an external hard drive and in an online cloud storage system.



Figure 4.4. Tobii Pro Glasses ii Mobile Eye-tracking Unit (Tobii Pro 2017).

Prior to the start of each trial, the device was outfitted with newly charged batteries and data from the previous recordings was transferred to the backup storage devices, clearing the SD cards. The Tobii device was then fit for each participant, using interchangeable nose pads and prescription lens adaptations as needed, with a calibration taking place after the fitting. Calibration of the equipment to each participants' gaze field was completed immediately prior to the trial. The calibration took place just outside of the entrance to the cave tour in a shed that was formerly a ticket booth. Visitors were instructed to wear the glasses for the duration of the tour and proceed as they normally would, unless any issues arose that made completing the tour in a safe manner

impossible. If needed, visitors were told they could take the glasses off and wear them around their neck with the attached lanyard to complete the tour, however, this did not occur for any of the trials.

4.4 Semi-Structured Interviews

In an effort to further understand visitor experience at the study sites, following each eye-tracking trial, participants were asked to participate in a semi-structured interview. Questions were validated in a manner similar to those used to validate the assessment instrument. Based upon the structure provided by Cohen and Crabtree (2006), the interviews used open-ended questions that related to the visitors' personal experience and observations during the cave tour. The interviews were recorded on a digital recording device and were backed up and transcribed at a later time. Interviews lasted no more than ten minutes and consisted of four to five open-ended questions:

- What do you believe about the role of cave tours in educating visitors on the environment?
- Discuss the information provided to you on the tour; content and deliverability
- Do you believe anything about the tour could be modified to provide for better education?
- What influenced your decision to visit here today?

Unfortunately, only 3 participants in Phase 1, 2 participants in Phase 2a, and 3 participants in Phase 2b, were willing to participate in formal interviews, due to time constraints with other tours.

4.5 Data Analysis

4.5.1 Pre- and Post-Assessments

As discussed previously, the pre-and post-assessments utilized in this study consisted of a mix of open- and close-ended questions modeled after assessment

instruments used by North (2011). Close-ended questions were evaluated by assigning a 1 for correct and a 0 for incorrect responses. Open-ended questions were similarly graded using a standard scale with only three values (Figure 4.5) to reduce subjectivity and allow for answers to be neither completely correct nor completely incorrect. The number of points earned on the assessment were divided by the total number of points possible, deriving the total assessment score. To determine the percent increase or decrease between assessment scores, the difference was calculated between the post-assessment and the pre-assessment scores for a single participant. This difference between the two scores was divided by the score of the pre-assessment and then multiplied by 100; the resulting value revealed the percent increase or decrease between the two attempts. An increase in score is assumed to represent that learning has occurred during the cave tour, while a decrease in score is assumed to represent incorrect information being given on the tour.

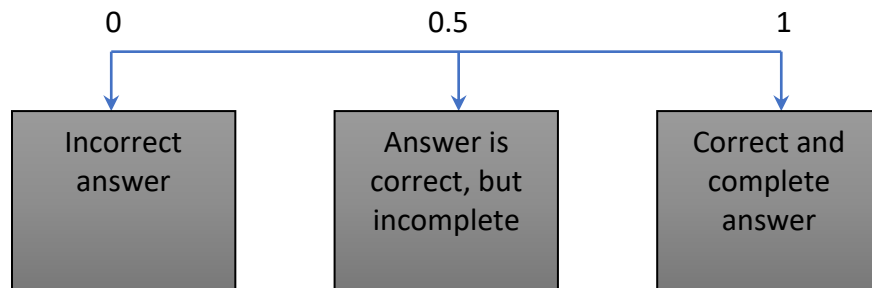


Figure 4.5. Grading scale for open ended questions. Created by author.

Statistical analysis software was used to process assessment scores; specifically, SPSS and SigmaPlot were used to run T-Tests and ANOVA tests. Standard measurements of central tendency were calculated on the change in pre- and post assessment scores for each sample (or population). The distribution and standard

deviation was calculated for the mean of scores. These statistical measurements were calculated for the entire sample population.

4.5.2 Eye-tracking Trials

In order to summarize the large sets of visual data the Tobii glasses collect, visual heat maps were generated using Tobii's analyzing software (Tobii 2016). Heat maps are beneficial in eye-tracking data analysis in that they allow a researcher to analyze common areas of interest through consideration of the amount and duration of fixations (Tobii 2016). As heat maps can only be generated ovetop of snapshot images, for this study, they were generated solely for static areas of common interest amongst visitors; in this instance, heat map were generated for pre-planned interpretive stops along the tour route.

While heat maps are advantageous for determining common areas of interest, they are not able to show sequence. In order to show sequence, gaze plots were developed for each participant. These figures are limited to the visitor experience at interpretive stops and provided useful visualizations to help understand the ways in which visitors comprehend interpretation along the tour. Through the development of gaze plots, the relationship between text and figures can be explored with respect to fixation duration and sequence (Tobii 2016). Both heat maps and gaze plots were generated using Tobii's analyzer software.

Heat maps and gaze plots are read in similar ways; depicting areas of high observation, but with different purposes. Gaze plots (example shown in Figure 4.6) are used to show location, order and amount of time spent looking at a location of interest. These can reveal the time sequence of looking, where and when visitors look at certain places. The duration of observation is show by the diameter of the circle; a longer

observation results in a larger circle (Tobii 2016). Heat maps (example shown in Figure 4.7) show the distribution of observations, where people are looking most frequently will occur as a hot spot on the map (Tobii 2016).



Figure 4.6. Gaze Plot example. Showing viewing location order and duration (larger circles indicate long duration) (Tobii 2016).



Figure 4.7. Heat map example. Areas with higher concentration of views shown as red “heat marks” (Tobii 2016).

The majority of analysis of eye-tracking data was observational since it was difficult to match up each participants' exact location at a stop with a static photograph. The researcher was familiar with the tour routes (due to having worked as a cave guide in previous years) and, thus, was able to make more detailed observations of participant gaze to find the common points of interest and sequence from different viewpoints. Other data recorded by the eye-tracking device, such as audio recordings, was transcribed and evaluated for trends among participants as part of this study through coding procedures. A study by Weston et al. (2001) revealed that coding is not a pre-defined method by which data are analyzed. Instead, coding is an active process of interpretation used to examine textual data (Basit 2003). The specific themes analyzed while coding semi-structured interviews or eye-tracking audio cannot be determined without first conceptualizing the responses and experiences of the participants. For this reason, the identification of themes did not occur until after the audio and video files were fully transcribed and reviewed.

4.5.3 Semi-Structured Interviews

As previously mentioned, there were not a large enough number of participants to allow for a complete analysis of semi-structured interview data. Nonetheless, initial interpretation of the interviews began with the process of transcription. During this period, the researcher listened to, recorded, and became familiar with the responses of the participants. After the interviews were transcribed, they were read a minimum of two times prior to the identification of themes; this process allowed the researcher to moderate any pre-conceived biases about the expected themes of the interviews. After the interview was read the second time, the researcher began to identify the themes presented

by the participants and the interviews were then coded by hand. The coded interviews were then analyzed using Methods of Agreement, a form of analytic comparison in which each individual case (cave tour) has a common outcome (education of karst systems) (Neuman 2013).

4.6 Limitations

While there are limitations that may exist in the research design of this study, every effort was made to ensure the methodology used in this study allowed for the collection and analysis of all data sets needed to answer the research questions. The greatest limitation for this study was visitation numbers for the study site, which were beyond the control of the researcher. Carter Caves State Resort Park received lower visitation during the 2018 summer season than the three prior seasons, limiting the number of participants. Another potential limitation of this study was the technology being used. Despite properly maintaining and using the mobile eye-tracking glasses, there were technological failures that the researcher was unable to solve, resulting in a partial data collected during phase 2b of this study. An additional limitation exists in the fact that eye-tracking participants were often distracted by their cellphones, often time taking pictures of the cave instead of just viewing it. Finally, there is the potential that use of the eye-tracking glasses may cause visitors to act out of character. While this was not observed to be an issue in any of the recordings, an effort to reduce this potential limitation was taken by seeking approval to withhold certain aspects of the study from participants, such as visitor's willingness to seek out and read interpretive signs, from the Western Kentucky University Human Subjects Review Board. This, as well as the

withholding the information regarding the glasses recording audio, was approved by the Human Subjects Review Board.

Chapter 5: Results and Discussion

The purpose of this study was to investigate the ways in which mobile eye-tracking can be used to enhance the educational experience of a guided show cave tour by studying the patterns in eye motion of cave visitors and understanding what visitors learn during tours. This study documented patterns in tour participants' eye motion during tours utilizing a Tobii Pro Glasses 2 mobile eye-tracking unit, assessed learning outcomes through pre-and post-outcomes assessments, and determined possible trends in visitor experiences through semi-structured interviews. Carter Caves State Resort Park, a state owned show cave in Kentucky, served as the study site for this research.

At Carter Caves State Resort Park participants were outfitted with a pair of Tobii Pro Glasses 2 mobile eye-tracking glasses and instructed to continue on a cave tour as they would normally. Other visitors were asked to complete a pre-assessment (see Appendix A) to test their knowledge on karst-related concepts prior to participating in a cave tour. After completion of a cave tour, both participant groups were given a post-outcomes assessment consisting of the same questions as shown on the pre-outcomes assessment, with the addition of five Likert-scale statements and demographic prompts to answer. In total, 27 eye-tracking participants were recruited over two phases of testing, as well as 90 respondents for the pre- and post-outcomes assessments. Demographics for both sets of participants are summarized in Table 5.1.

Table 5.1. Demographics of all participants.

Residence		Education Level		Age		Gender	
CA	1	HS	19	18-30	25	M	44
KY	44	Some College	30	31-40	29	F	62
WV	16	Associates	8	41-50	18	No Response	8
OH	19	Bachelors	19	51-60	13		
IN	3	Masters	13	60+	18		
MI	1	PhD	2	No Response	11		
SC	2	No response	11				
IL	3						
FL	2						
MO	2						
Outside of US	1						
No Response	23						

Throughout the various phases of this study, a total of 53 “no response” were submitted to several of the demographic questions (age, gender, residence, etc.) on the assessment instrument. In total, of the 90 responses collected for all three phases of study at Carter Caves, 11 participants did not respond with their age, 8 provided no gender information, 11 did not indicate an education level, and 23 failed to provide a location of residence. A lack of response on demographic questions may have been the result of the demographic questions being the last section of the assessment instrument and participants were running short on time to complete the assessment. Meade and Craig (2012), for example, found that survey length, participant interest, and environmental distractions all have an impact on how well survey participants respond to a survey

instrument. In a similar study of web surveys by Galesic and Bosnjak (2009), the positioning of certain questions within a survey instrument affects quality responses; specifically, when close-ended multiple-choice questions were first, with open-ended questions last, responses to the open-ended questions often were lacking in detail when compared with surveys with the open-ended questions positioned first. While the assessment instrument used in this study consisted of only seven questions (with four open-ended), the remaining 12 were demographic questions, taking up two pages total. When considering that many participants may have been on a tight schedule to meet other tour times, travel times, etc., this may have created a lack of interest in the post-assessment. The area in which the assessment was given was also not ideal for participation since the meeting point for tour departures, the location where assessments were completed, was often crowded and loud with kids running around and shouting. This would could have been distracting to the respondents, which may also been a reason for not completing the full assessment.

5.1 Guide Information and Training

The interpretation provided by the guides at Carter Caves State Resort Park is the only current method for any visitor to learn information about the park; there are no interpretive signs, pamphlets, brochures, etc. freely available at the park that go into detail about the geology of the area. When combined with the fact that the guides are given a very loosely structured training period (essentially just shadowing a guide who has been leading tours for at least one season for several days until they feel comfortable leading a solo tour), it is clear a strategy for improved visitor education should be implemented at the site. While there is plenty of scientific literature about the local

geology, history, and biology, the guides are never tested on their knowledge; the park naturalist trusts the older guides are properly training the new ones. This relaxed method of training seems to allow some guides to flourish and others to not. It is possible that due to this method of training, the guides who have been leading tours for longer will likely result in providing more accurate information, while newer guides may struggle to learn the concepts themselves. This may also mean that incorrect information could be perpetuated by being passed down from guide to guide. This was beyond the scope of this study, but should need to be studied in more detail.

Throughout the study, five guides led tours in which data were collected: J, L, W, M and K. An effort was made to keep the same guides throughout each phase of study, but due to scheduling for the park this was not entirely possible. Guides J, L, M and W gave at least three tours per phase of study, while Guide K was only studied for the first two phases. Due to the differences in tour sizes throughout the study, it was not possible to have the same number of participants for each guide, per phase of the study. In order to standardize the sample size across all the guides, the results from participants were averaged for data analysis purposes.

When viewing the audio and video recordings for Phase 1, Guide L was observed to seemingly understand the content; he stated simplified, but accurate, information. An audio recording taken from EP1.2 has Guide L, who had the least experience of the studied guides, discussing how stalactites and stalagmites form: *“Water that has been leaking into the rock overheard through small openings are able to dissolve the rock, which has calcium in it. That calcium then re-solidifies as the water slowly drips in to the cave”*. From this, Guide L clearly demonstrates his understanding of the processes

involved with speleothem formation and that he can simplify the content for the general public. He would, however, frequently change his tours to suit the audience wants, such as more causal talk and jokes when audiences seemed less interested in standard tour content. In the same recording from EP1.2, shortly after the previous excerpt, Guide L was observed being somewhat frustrated with having no responses from the tour group; specifically, after having asked if there were any questions several times with no results, he resorted to jokes, which successfully got a laugh. He stuck with the theme of frequent jokes, rather than detailed content, for the remainder of the tour. This is in contrast to Guide J, the longest serving cave guide who participated in this study, who would tend to stick to providing more information about the cave environment during the tour. His strategy seemed to be to initiate and finish all casual conversations with his tour participants during ticket collection.

Guide W, a former science teacher, was a fairly new tour guide at the time of data collection, having lead tours for two years. Guide W was exceptional at using his teaching background to ensure visitors understood the concepts during the cave tour. From the collected audio and video recordings, Guide W frequently used the most interpretation techniques out of all the guides. He was able to evoke reactions from the visitors without resorting to jokes; for example, he would often make visitors “gasp” or otherwise react when referencing the massive timeframe it took for cave formation by relating it back to human timescales. Guide W was the only guide to mention the word ‘karst’ during a tour from the first phase, using it while referencing the “karst window” seen in the Lakeroom. He described karst as: “*rock landscapes that typically form caves*”.

Guide K, who had been leading tours the same amount of time as Guide W, led somewhat basic tours, with his information seeming ‘rehearsed’ as though he was repeating verbatim the same information he was given during training. As revealed during an interview, Guide M, who had been leading tours for three years and was a college student, read his own supplemental training information from Lierman et al. (2011) and used information from this paper on his tours. From observations, Guide M was the only guide to mention the relative ages of the rock layers or provide tour participants with any information about sinkholes.

As revealed through the eye-tracker audio recordings, all guides were very good at discussing speleothems and points of geologic interest in the cave, but often lacked content relating to the broad picture of the interconnectedness of karst landscapes. None of the guides referenced how easily karst landscapes could be polluted or how easily water could move from the surface to the subsurface. Table 5.2 shows the assessment score increases between pre- and post-assessments based on guide and tour group size from Phase 1. Using the assessment score and eye-tracking audio and video data from Phase 1 of the study as a guide, a basic script for the tour guides was constructed for later use during Phase 2b. The script was created for enhancing targeted learning outcomes, while also maintaining the entertaining and fun aspects of the guides. The eye-tracking audio data was also used to determine the best methods of guide interaction with tour participants in an attempt to not sound “scripted”. The common interest points previously established and used for the pamphlet in Phase 2a were again used for Phase 2b to create the main content discussed.

Table 5.2: Phase 1 summary of percent increase in pre and post assessment scores.

Size of group (number of respondents) Education Level	Average of %Increase	Size of group (number of respondents) Education Level	Average of %Increase
Guide J		Guide W	
11-20 (7)	352.98%	0-10 (2)	32.22%
40+ (3)	0.00%	21-39 (3)	97.78%
Guide K		Guide M	
40+ (4)	34.86%	21-39 (7)	93.39%
Guide L			
11-20 (1)	2.22%		
40+ (3)	-83.33%		

Visitor reactions to guides during Phase 1 varied. Four questions on the post-assessment used a Likert-scale; these questions asked for visitor opinions on overall satisfaction, quality of education, tour enjoyment, and quality of tour guide. These results are presented in Table 5.3. Guide W resulted in the highest scores, receiving an average score of 4.79, likely due to his experience with interpretation. Guide L ranked second highest, with an average score of 4.48, despite having one of the lowest scores for quality of education. Guides J, M and K had comparable average scores, but Guide K had the lowest quality of education score of 3.25. These results suggest that there is a possible relationship between how long a guide has been educating in some capacity (in a classroom, on guided tours, etc.) and the quality of training and the quality of education the guide provides on tours.

Table 5.3. Results from the four Likert-scale post-assessments questions of Phase 1.

GUIDE (Years worked)	SATISFACTION	EDUCATION	ENJOYMENT	TOUR GUIDE	Average Score
J (10)	4.56	3.67	4.56	4.22	4.25
W (2)	5.00	4.60	4.75	4.80	4.79
K (2)	4.50	3.25	4.50	4.75	4.25
M (3)	3.80	4.75	4.10	4.30	4.24
L (1)	5.00	3.40	5.00	4.50	4.48

5.2 Eye-tracking to Identify Common Interest Points

During Phase 1, the most popular visitor observations and areas of interesting observation patterns were found and compared throughout the phases of this study to reveal differences in visitor understanding. These areas were also used to develop the pamphlet for Phase 2a. Unfortunately, due to technological failures with the mobile eye-tracking glasses utilized in this study, Phase 2b was incomplete and unable to be used for comparisons with the prior phases; however, the differences between Phase 1 and Phase 2a reveal interesting results as to what visitors observe and how they are observing the cave environment during a tour.

All images used as the background of eye-tracking heatmaps were created using still images taken at the start of Phase 2a, at which time the lighting had been altered in the cave (see section 5.3). Due to the complexities of accurately matching the eye motions of a visitor walking in a large three-dimensional area to a static image, only a select few locations that are used as interpretive stops most frequently were analyzed in depth with combined heat maps from all participants. While this was a goal of the study, achieving it with this show cave was not possible. Interpretive stops allow for some “standardization” of the visitors. The stops within the studied cave tour are somewhat

limited due to the size of passages and rooms, as well as the amount of possible visitors on tours; at other show caves, it would likely be possible to determine new locations for stops using mobile eye-tracking data depending on the size of the cave. Two areas of significance stand out when analyzing the eye-tracking recordings: a room in Cascade Cave known as the Lake Room (Figure 5.1) and an area showcasing an offshoot passage known as Cascade Avenue (Figure 5.2). These areas appear significant due to the interesting patterns of eye movement revealed from the eye-tracking data analysis; specifically, most visitors observed the same spots, in essentially the same order. Fortunately, these areas were also locations of interpretive stops and excellent locations to demonstrate the importance of karst landscapes. These areas were occasionally skipped due to the large sizes of the tour groups, a factor that will be discussed in a later section.



Figure 5.1. The Lake Room of Cascade Cave. (Image captured by author).



Figure 5.2. Cascade Avenue of Cascade Cave. (Image captured by author.)

The Lake Room is an area that showcases many incredible features found in karst areas and has the perfect environment to showcase the interconnectedness between the surface and subsurface in karst areas. A large creek flows through this room and then out through an opening in the cave to a forested area. This is a room where guides can talk about potential pollution from human activity, the nature of underground water, and much more. Unfortunately, however, as documented in the eye-tracking recordings (audio and video) during Phase 1, this room was occasionally passed through quickly due to the group being large and/or the inability of the guide to speak loud enough for all visitors to hear. If the room was discussed, guides would only mention the potential of the room to flood and the large speleothems hanging from the ceiling. One of the guides disregarded even these topics in lieu of discussing a time when they saw a fox running

out of the opening when the water was low and then proceeding through the cave. This resulted in sporadic viewing of the room, with visitors' gazes frequently darting to a large, bright opening to the outside, despite the guides only briefly mentioning it, and often to their footing. Figure 5.3 shows the summed results from the ten eye-tracking participants in Phase 1 in the Lake Room. During this phase with the pointed lighting visitors most frequently viewed the cluster of formations along the ceiling, the emergence of the creek from under a walking bridge.



Figure 5.3. The Lake Room of Cascade Cave with visitors' observations from Phase 1 overlain. Areas of high observation are shown with red, lower observations are faint green. The large clustering to the left indicates when participants were observing the opening to the outside, the clustering of colors (indicating observations) to the bottom of the image represents when participants were observing their footing. (Background image captured from eye-tracking video, heat map generated from eye-tracking video data, created by author).

The second area of interest in this study, Cascade Avenue, revealed some surprising visitor behavior. Cascade Avenue is a large, elliptical tube passage with various speleothems throughout, as well as large collapsed floor sections. Visually, it is a very striking section of cave, and often one of the most photographed areas inside the cave. Cascade Avenue is an excellent location to discuss cave formation; the flowing body of water that carved it out is still present, one level below, flowing under the bridge visitors stand on to view the Avenue. Visitors must stand on a small bridge, about two feet wide and 25 feet long to see straight down the passage. Despite these difficulties, the pattern of visitor observation in this section of cave is very distinct. While the same pattern of looking towards the brightly lit areas occur, eye-tracking participants appeared to also observe the shape of the passage. Figure 5.4 shows the eye-tracking results of the ten participants from Phase 1; large clustering to the bottom of the image indicates participants observing their footing. The large clustering at the center of the passage is likely visitors being interested in the length of the tunnel and curiosity about how much further it reaches.

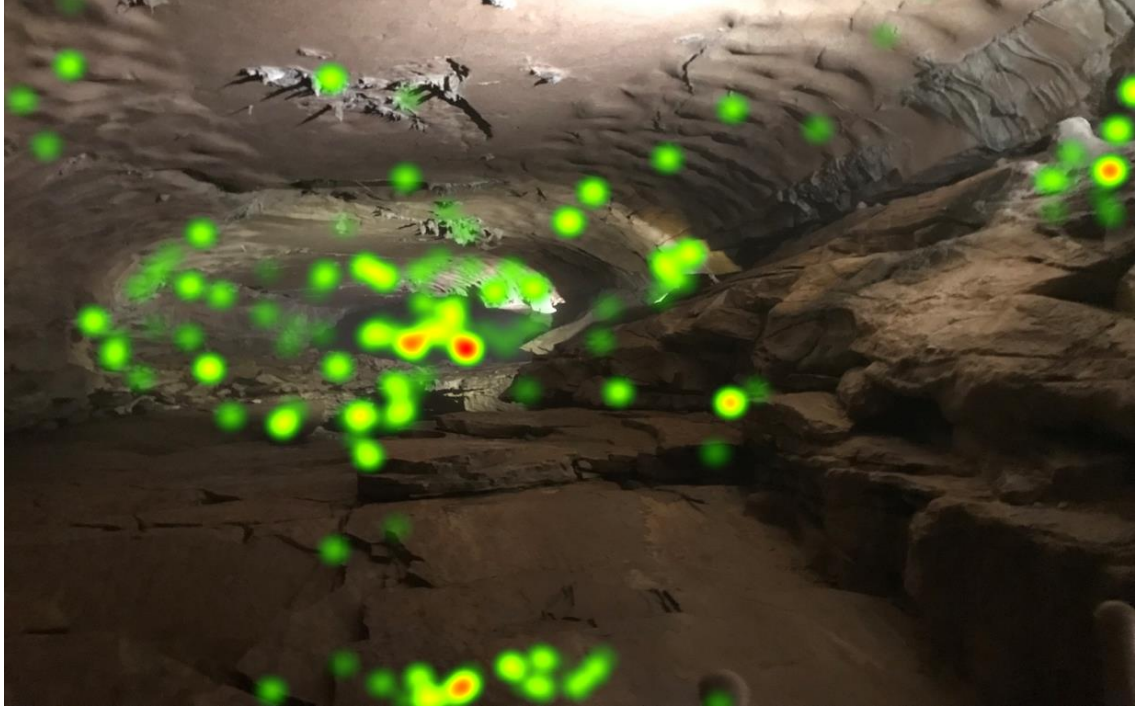


Figure 5.4. Phase 1 eye-tracking results in a heatmap of Cascade Avenue. Areas of more observations are shown in red, fading green is lower observations. (Background image captured from eye-tracking video, heat map generated from eye-tracking video data, created by author).

Phase 2a had the same number of eye-tracking participants as Phase 1, but not necessarily with participants viewing the same location. For instance, during tours with large groups (over 35 people), tour guides will sometimes skip locations that are too small for the entire group to see all at once. This happens most frequently at Cascade Avenue, where groups will stop on a small bridge to see the same view of Cascade Avenue as shown in the heat maps. With larger groups, or sometimes even just loud groups that the guide cannot speak over, this section will be skipped entirely, which resulted in less accurate heat map results due to the shorter observation times. Figure 5.5 shows the heat maps results from Phase 1 and 2a of Cascade Avenue. Phase 2a is overlain in blue on to Phase 1 results. Aside from the differences in locations observed, which are discussed in a later section, there is an overall lighter density of Phase 2a gazes

(shown in blue) due to this section being skipped most frequently with larger tours.

Despite the limited amount of views, this data is still useful in showing patterns of visitor observation and also suggests a relationship between size of tour group and the visual experience tourists have within a cave.

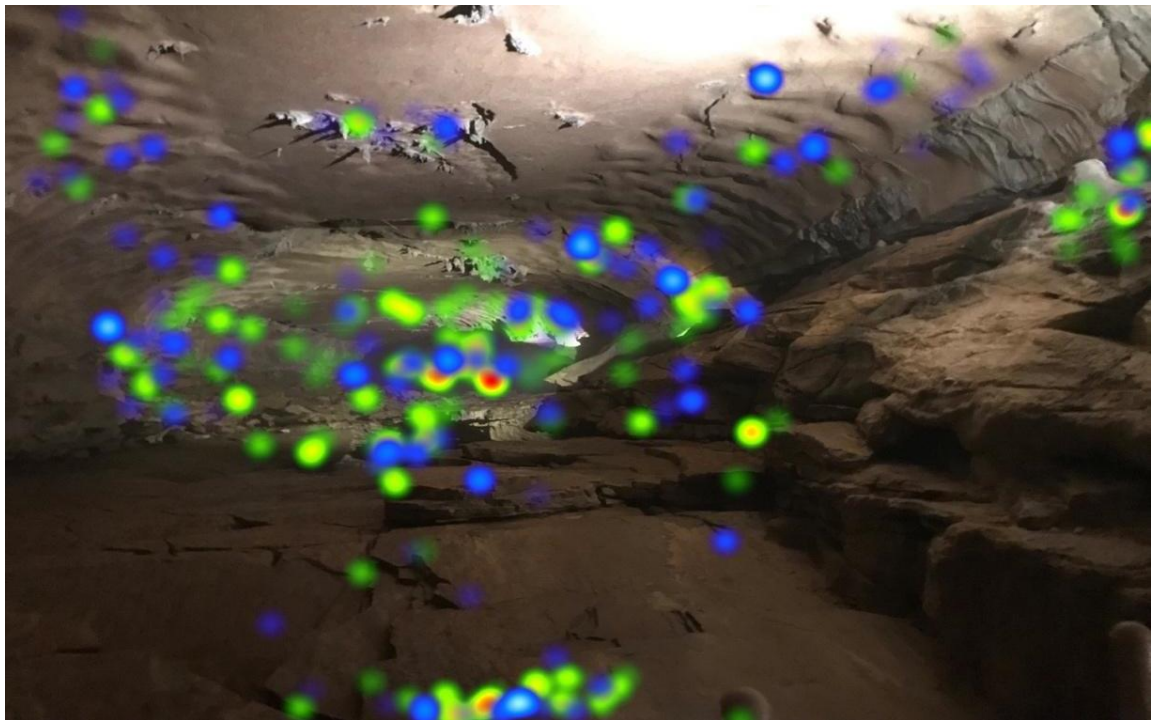


Figure 5.5. Phase 2a results overlain on to Phase 1. Phase 2a areas of observations are show as white/blue, with dark blue indicating areas with fewer observations. (Background image captured from eye-tracking video, heat map generated from video data, created by author).

Ultimately, the eye-tracking glasses utilized in this study were able to identify common points of interest amongst visitors in the rooms, as well as locations for missed educational opportunity when. However, the eye-tracking glasses were less useful in areas along the walking route. These results will be analyzed and discussed in more detail in a later section.

5.2.1 Development of Walk-Along Pamphlet

The goal of this study was to find out ways to improve education on guided tours using eye-tracking technology and other educational tools. When comparing this study site to counterparts, such as Mammoth Cave National Park, this site lacks interpretive and educational materials beyond that of the guided tour. Other sites may use resources, such as museums displays or interpretive signs, among others educational tools, to provide educational materials to cave guests. Creating interpretive material such as signs or museums was unrealistic for the scope of this project, therefore, a “walk-along” pamphlet was created using eye-tracking data collected in Phase 1.

Using a combination of the eye-tracking data and discussions with the Park Naturalists, the informational pamphlet for Cascade Cave was created. This two-page packet was meant to be used by visitors prior to and during their cave tour. The first page included general introduction to karst landscapes, why they are important, as well as information on how karst areas form. Material on the second page was laid out in the order it would be seen on the cave tour, allowing visitors to read information about the objects and locations they were seeing in the cave in an easy to follow manner. Prior to distributing the pamphlet with the public, it was reviewed by several cave guides at Mammoth Cave, the Carter Caves Naturalist, as well as students at WKU to ensure the material was simple enough for the general population to understand.

While the Cater Caves Park Naturalist had certain concepts he wanted covered in the packet, park staff allowed the eye-tracking analysis from Phase 1 to determine the majority of the content. The only item in the packet that was not from eye-tracking participant data was the inclusion of the information on the many small sinkholes in the

immediate area. Other areas were included due to frequent observations by participants or mention of them in post surveys and post assessment questions. These were topics such as the bat roosting areas and the large pole in the North room, while others were included due to being main tour stops that were occasionally skipped over, such as Cascade Avenue and the Lakeroom.

Pamphlets were distributed to all eye-tracking participants and assessment respondents (after finishing their pre-assessment), as well as any other interested visitors. Participants were encouraged to read their pamphlet while on the cave tour and were allowed to keep them after the tour concluded, however, they were not allowed to use them while completing their post-assessments. The pamphlet used in this study can be seen in Appendix B.

5.3 Cave Lighting

From preliminary testing, it was known that the lighting in Cascade Cave of Carter Caves was effective enough to allow for this study, since an average of 75% collection rate of gaze samples was collected by the eye-tracking instrument used in this study during three test runs by the researcher. During the first phase of this study, the lighting of the cave tour was significantly different than the lighting used during the subsequent phases. Specifically, during the first phase of the study, the study site at Carter Caves had very direct, pointed lighting meant to highlight a specific feature of the cave or certain safety concerns around the room (e.g., a low hanging rock along the tour route). During the break between phases of study at the end of June 2018, the lighting used in the cave was changed to be more diffuse and ambient, lighting the areas of the cave essentially equally, with extra emphasis on the trail. In part, this change in lighting

resulted from conversations with the park naturalist at Carter Caves which emphasized concerns Phase 1 eye-tracking participants had with the cave lighting. A comparison of the lighting prior to and after June 2018, can be seen in Figures 5.6 and 5.7, respectively.



Figure 5.6. Image of Cascade Avenue prior to the installation of new lights (Image by author).



Figure 5.7. Image of Cascade Avenue after to the installation of new lights (Image by author).

5.3.1 Impacts to Visitor Observation

The results from Phase 1 of this study were similar to what was hypothesized, with visitors looking at their footing and following the brightly lit spots inside the cave. Phase 1, which consisted of ten eye-tracking participants, revealed that visitors' gaze followed along with what the guide was saying, but their attention fixated more frequently at bright areas. For example, in Figure 5.8, which shows a room in Cascade Cave of Carter Caves generally referred to as "The Formation Room", is the gaze map of EP1.5. When watched along with the audio, their gaze follows what the guide is discussing. For instance, if they are observing the main speleothem in the room at position 8, then their gaze switches to position 9 at another speleothem when the guide begins to talk about it. Yet, their gaze drifted frequently to brighter lit areas of the cave

passage despite the guide still talking about the speleothems (positions 4, 5, and 11). This general pattern of eye gaze emerged throughout the data set, where the participants followed what the guides were saying, but seemingly got distracted by the other areas that were brightly lit. During Phase 2a, after the lighting changed, this same pattern emerged, but to a lesser degree. Visitors would still drift their gaze to the brightest points on occasion, but they would also scan larger swathes of the room or area they were in, as shown in the heatmap of the Formation room (Figure 5.9).

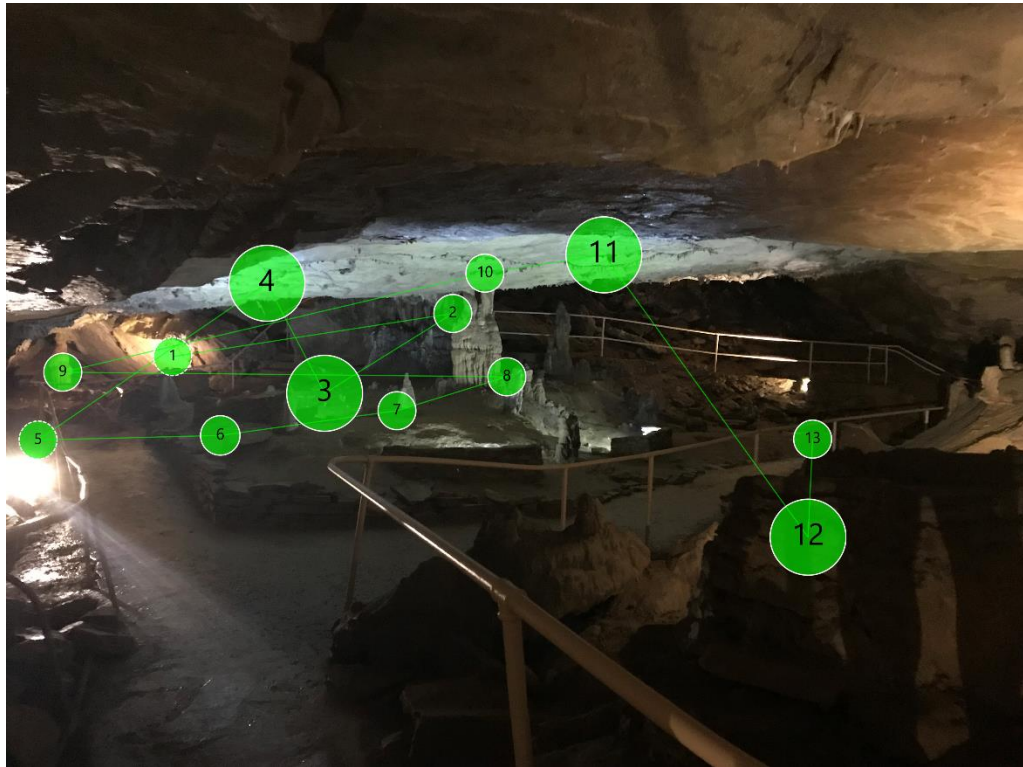


Figure 5.8. Gaze map of the Formation Room of Cascade Cade. (Gaze map image generated by author from eye-tracking video data).



Figure 5.9. Heatmap of the Formation Room showing Phase 2a with Phase 1 eye-tracking data. Phase 1 areas of high observation are shown with red/yellow, lower observations are faint dark blue, Phase 2a areas of high observation are white/blue. (Heatmap image generated by author from eye-tracking video data, background image by author).

When analyzing the Lake Room eye-tracking results from Phase 2a, in which the pamphlet create for this study included information about the creek, it is clear visitors with the eye-tracking glasses observed the creek more than the Phase 1 eye-tracking participants. Observations of footing and the opening to the outside still occurred, as well as observations of the speleothem located in the cave room, but there is a clear concentration of observations along the creek passage. Figure 5.10 shows Phase 2a transposed in blue over top of Phase 1 eye-tracking data in the Lake Room of Cascade Cave. This is likely the result of a combination of the lighting change and the inclusion of the pamphlet. At least two eye-tracking participants were observed reading the pamphlet

while walking through the cave. For comparison of the lighting, a screen capture from a Phase 1 eye-tracking participant, before the lighting change, is shown as Figure 5.11.

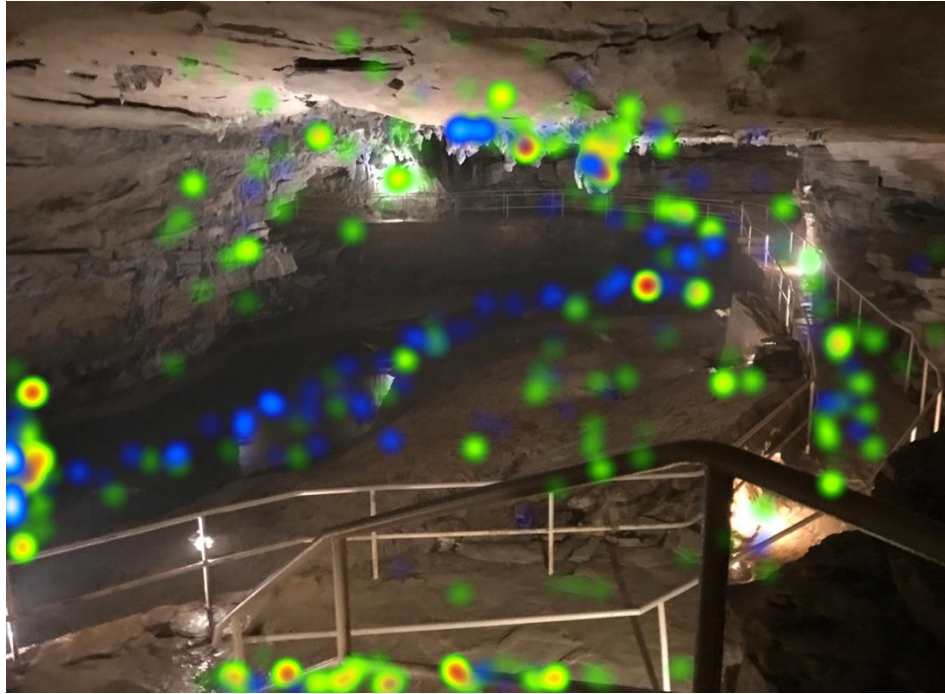


Figure 5.10. The Lake Room of Cascade Cave with visitors' observations from Phase 1 and Phase 2a overlain. Areas of high observation are shown with white/blue, lower observations are faint dark blue. (Heatmap image generated by author from eye-tracking video data, background image by author).



Figure 5.11. The Lake Room of Cascade Cave prior to new lighting. (Image captured by author from eye-tracking video).

Results from Phase 2a of Cascade Avenue, where this passage's phreatic tube (the shape of the passage is oval shaped) and its formation were discussed in the pamphlet at length, reveal visitors' being focused on the shape of the passage, and surprisingly the features known as scallops in the rock walls lining the passage. Views are less focused on the back end of the passage and more on the surrounding features, likely due to the lighting changes which more brightly lit the entire cave passage (Figures 5.12). Lighting may, however, also draw the attention away from important cave features if not properly designed. For example, collected data revealed instances in which areas frequently observed by eye-tracking participants during the Phase 1 (noted as the red spots on heat maps) were rarely observed by Phase 2 eye-tracking participants seemingly due to the lighting changes.

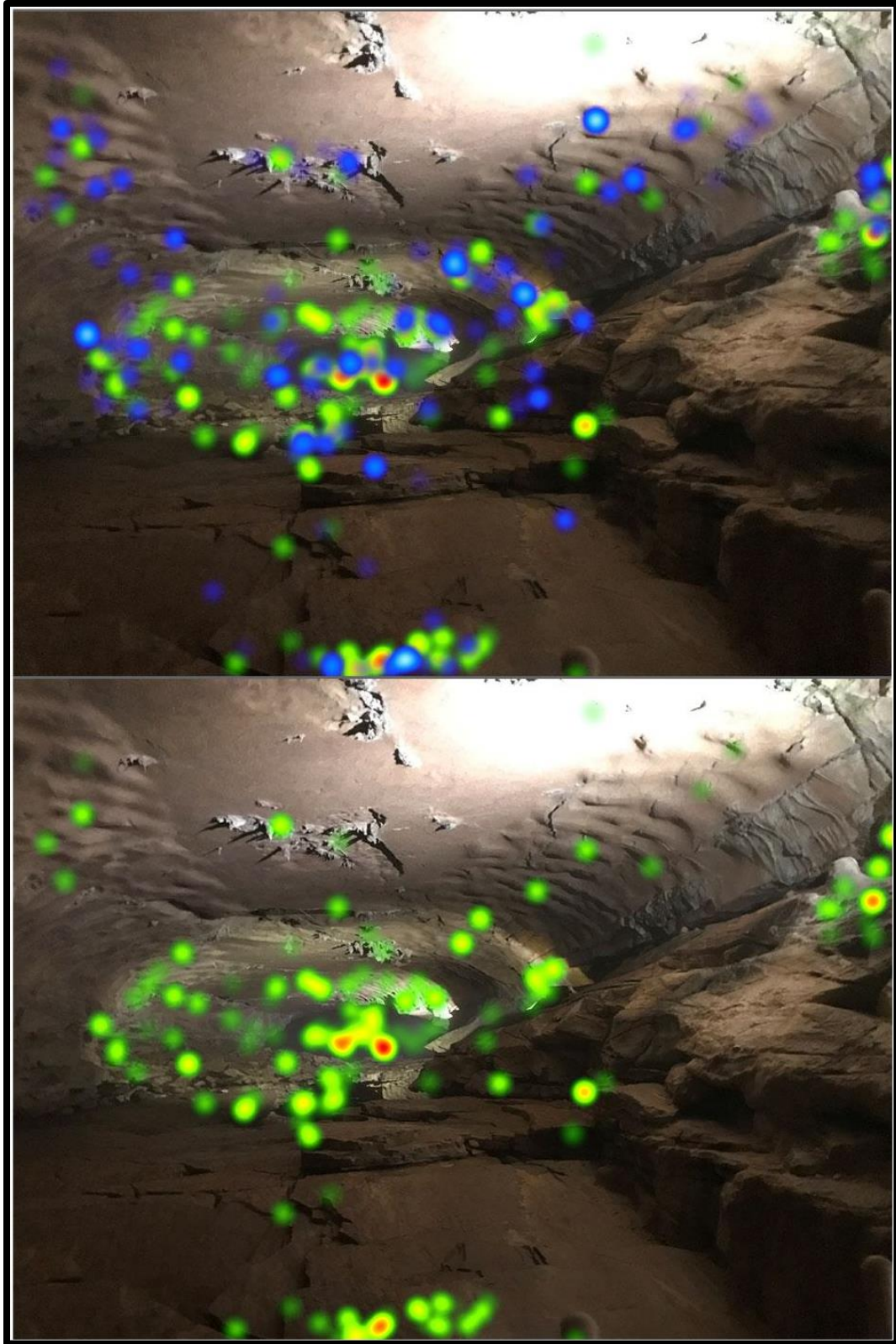


Figure 5.12. Eye-tracking data from Phase 2b overlain onto Phase 1 data. For ease in viewing, Phase 1 data only are shown in bottom image. (Heatmap image generated by author from eye-tracking video data, background image by author).

Another possible outcome of altering the cave lights may be visitors' awareness of their surroundings. During Phase 2a, Participant EP2.10 noted that their companion was close to walking right on top of an old, broken speleothem on the floor, after which they moved around it (Figure 5.13); this could also be due to Participant EP2.10 being more aware of the initial rules and regulations, but this behavior had not been observed by any prior eye-tracking participants. In contrast, during the first phase of this study, there were more participants observed touching the cave walls or speleothems, a direct violation of the stated rules.

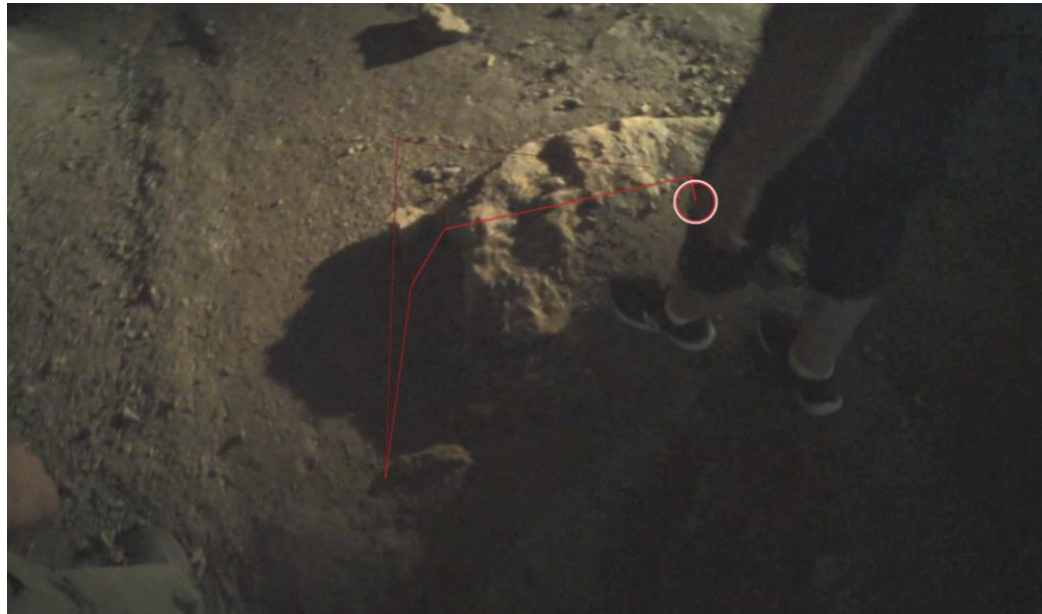


Figure 5.13: EP2.10 observing the speleothems on the ground and warning companion to not step directly on it (Image captured by author from eye-tracking video).

5.3.2 Impacts to Visitor Safety

Most of the Carter Caves tour route through the cave is either paved with concrete or stepping stones, a trail that blends in very well with the cave floor and appears rather bumpy in the initial cave lighting in operation at the beginning of the study, and includes handrails in areas that have historically had many safety issues. During Phase 1 of the

study, there was one instance of survey respondents feeling unsafe due to lighting and nine instances recorded with the eye-tracking videos of the participants (or discussed in their post interview), when the participant, their companions, or other visitors stated they did not feel the trail was adequately smooth or lit and there should be hand rails. Table 5.4 shows visitor themes relating to safety from Phase 1. These data reveal the ability of an eye-tracking tool to collect information that guests may otherwise not share on a survey instrument.

Table 5.4. Visitor themes relating to safety from Phase 1 of study, showing occurrences of visitors stating concerns for safety during the cave tour.

	Instances per Tour Group										
Phase 1 Survey Respondents	1	2	3	4	5	6	7	8	9	10	Total
Felt unsafe											
a) Due to lighting									1		1
	Instances per Tour Group										
Phase 1 EP Audio Recordings/Interviews	1	2	3	4	5	6	7	8	9	10	Total
Felt unsafe											
a) Due to lighting	1	2		1			1		2		7
b) Wet stairs/path	1					1					2

While the purposes of this study were not necessarily to study the impact of the visitor learning outcomes as a result of site development, the study revealed the development of the site might play a key role in learner outcomes, particularly in regard to lighting on the trail and trail development. For example, visitors must feel safe enough to walk throughout the show cave to be adequately engaged with the tour. Prior to new lighting, visitors commented on the lighting much less frequently, with only one occurrence from a participant aged over 65. It is likely this issue is a larger concern than

indicated by the survey results, as the question was open ended towards the end of the assessment and possibly not on the mind of the participant at the time the assessment was completed.

5.4 Visitor Learning Outcomes

At the Cascade Cave study site in Carter Caves State Resort Park, 30 individuals per phase, for a total of 90 participants, completed a pre- and post-outcomes assessment. There were also 27 individual eye-tracking participants who only completed a post-outcomes assessment, which were discussed previously. Analysis of pre- and post-assessment data provided insight into visitors' expectations, experience, and learning outcome while on the cave tour. The pre- and post-assessment scores were analyzed by several individual variables, such as participant age, gender, willingness to learn (indicated in survey), and by tour logistics, such as their specific guide and the size of the tour. Assessments were scored using the methods discussed previously, with a maximum possible score of five.

The responses gathered from Phase 1 of this project were used to help determine the material in the pamphlet that was used during Phase 2 of the study. Upon initial inspection of the data, an increase in total outcomes assessment score from the respondents was higher, indicating that they learned while on their cave tour. Average score increases for Phase 1, Phase 2a and Phase 2b were 117.25%, 262.22%, 161.65%, respectively. Statistical analysis using Paired T-Tests and ANOVA tests were performed to quantitatively analyze the pre- and post-assessment scores for all three phases of the study. Pre-assessment scores throughout the three phases were all found to be consistent with true random sampling and not have a statistically significant difference in scores,

ensuring that there were no anomalies when comparing the scores such as visitors with prior knowledge. Eye-tracking participants, who were only distributed the post-assessment to limit bias, had scores with no statistical difference to the average from those who took both the pre-assessment and the post-assessment; this indicates that not only were the eye-tracking glasses not a hindrance for cave visitors, but also the bias the pre-assessment participants may have when taking the tour and being more prepared for the post-assessment is negligible. These results are summarized in Table 5.5.

Table 5.5. Eye-tracking participants average post assessment scores compared to assessment taker only participants post scores.

Phase 1		Phase 2a		Phase 2b	
Post 1 Avg (Assessments only)	2.38	Post 2a Avg (Assessments only)	3.52	Post 2b Avg (Assessments only)	2.70
Post 1 Avg (Eye-tracking)	1.94	Post 2a Avg (Eye-tracking)	3.68	Post 2b Avg (Eye-tracking)	3.13
StdDev	0.22	StdDev	0.12	StdDev	0.30

5.4.1 Phase 1 “Control”

Phase 1 of this study was used to establish and understand the base knowledge of the general public relating specifically to karst landscapes. The initial survey results from Phase 1 of the study indicate that many visitors do not have any basic karst knowledge before the tour, and upon completion of the tour, still have not learned much about the environment. With results from paired T-Tests indicating there was no statistical difference between the pre- and post-outcome assessment scores, with a T-Value of -1.58 and a P-Value of 0.119. The average scores for this phase were 1.74/5 for the pre-

assessment and 2.38/5 for the post-assessment, for an average percent increase of 117.22%. Results are summarized in Table 5.6.

Table 5.6. Phase 1 survey participant score analysis. Data shows comparisons between pre- and post-assessment scores, Differences between means, Standard Deviation, and Standard Error of Mean (SEM).

	Mean	Std Dev	SEM
Pre 1	1.726	1.359	0.240
Post 1	2.281	1.364	0.241

When scores from Phase 1 were analyzed by individual guides, there is a noticeable difference in several score results. These results support the earlier hypothesis that guides who are newer to leading tours resulted in lower scores compared to guides that have been working with the park longer (Figure 5.14). Other variables were analyzed, such as visitor ages and genders, with group size producing a noticeable pattern, which will be discussed in a later section.

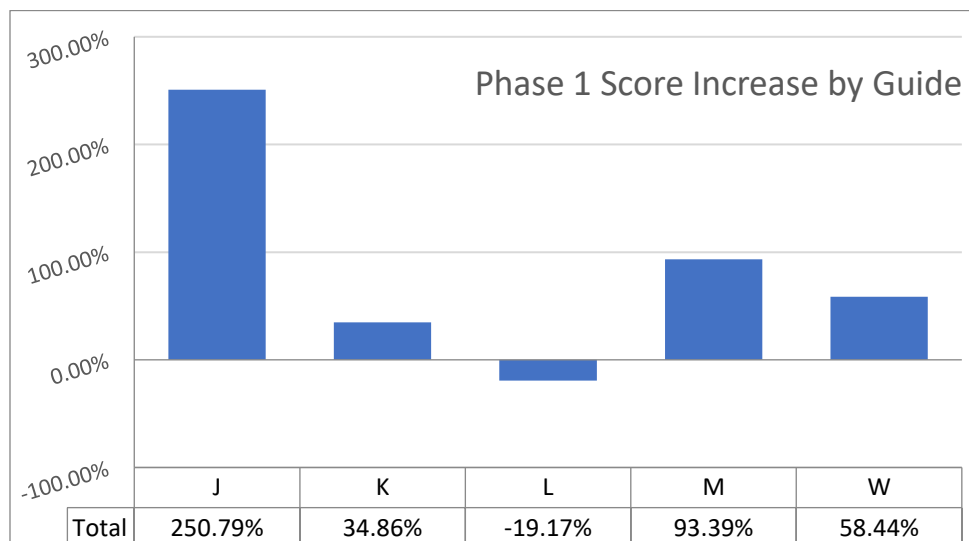


Figure 5.14. Average percent increase between pre and post assessments by guide. J has been guiding tours at CCSRP for 10+ years, K for 2, L for 1, M for 3, W for 2.

5.4.2 Phase 2a “Walk-along pamphlet”

The content delivered by the guides during Phase 2a of the study did not change; guides were instructed to provide the same tour they have always. Using the audio recording from the eye-tracking trials it was confirmed that the guides did not alter their content from their regular tours. During this phase, after completion of the pre-assessment, the visitors were given an informational brochure (Appendix B) that discussed karst landscape of the area and the unique features found within the cave being toured. Visitors were encouraged to use the brochure as a follow along companion to their tour but were discouraged from using it while taking the post assessment.

Assessment score data from Phase 2a shows a statistically significant difference between the pre- and post-assessments, suggesting the brochure did play a role in better educating the public (Table 5.6). Data collected during Phase 2a of this study revealed an overall increase in scores by a statistically significant amount, with average scores of 3.445 2.281 for the pre- and post-assessments of Phase 2a, respectively, as shown in Table 5.8, along with the differences between means, T value, and probability. The pre-scores were comparable to Phase 1 with a difference in average score of 0.0803, the post scores were higher with an average percent increase of 262% compared to 117% from Phase 1. Score comparisons between Phase 1 and 2a can be seen in Table 5.8.

Table 5.7. Phase 2a Respondent only score analysis, showing score comparisons between pre and post, Differences between means, Standard Deviation, and Standard error of mean.

	Mean	Std Dev	SEM
Pre 2a	1.258	1.378	0.244
Post 2a	3.445	1.264	0.223

Table 5.8. Respondent only score analysis, showing score comparisons.

COMPARISON	DIFF OF MEANS	MEANS	T	P
POST 2A VS. POST 1	1.164	3.445 / 2.281	3.971	0.002

When analyzing score by guide (Figures 5.15 and 5.16), all participants performed noticeably better on the post assessment. The researcher and assistants present discouraged participants from using the pamphlets information while taking the post assessment and did not observe any participants using them. Scores from Phase 2a make it apparent the pamphlet provided exceptional education to most of the tours, due to the significant increase in the scores for most of the guides. However, Guide J's tours for Phase 2a performed improved slightly less than Phase 1, with no reason abundantly clear after analyzing the results. The demographics for Guide J were comparable to those of the other guides, as well as the sizes of the tours. Guide J did lead more tours for this phase, which lead to a larger sample size, which was accounted for using repeated measure ANOVA tests. A summary of the Likert-Scale questions from Phase 2a in Table 5.9.

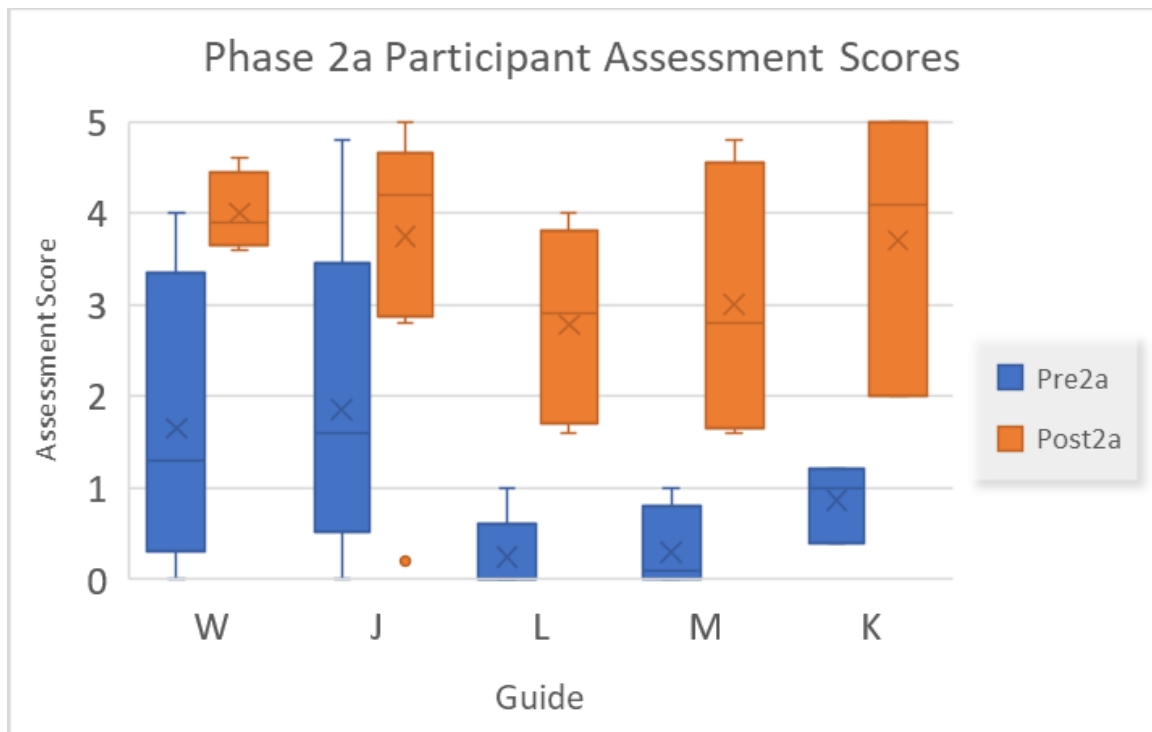


Figure 5.15. Phase 2a assessment respondent scores by guide. Graph shows the minimum and maximum scores, as well as the average for each guide indicated by the X (created by author).

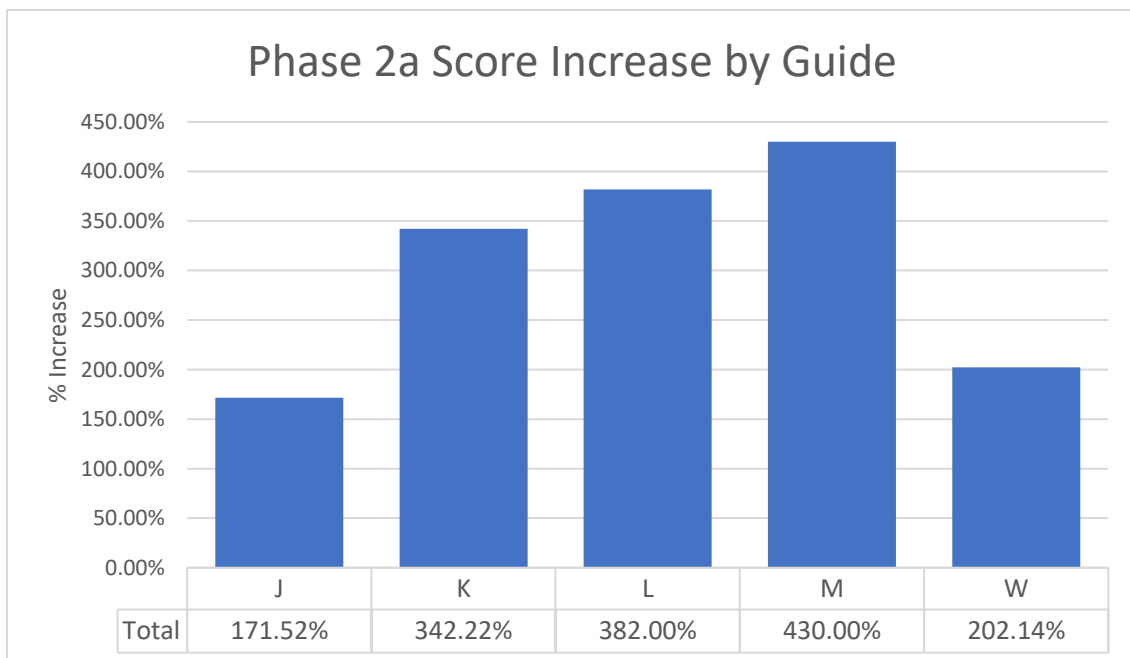


Figure 5.16. Phase 2a assessment score outcome increase by guide (created by author).

Table 5.9. Results from the Likert-Scale questions from the post-assessments of Phase 2a.

Guide (Years worked)	SATISFACTION	EDUCATION	ENJOYMENT	TOUR GUIDE	Average
J (10)	4.55	4.18	4.73	4.82	4.57
W (2)	5.00	4.00	4.75	5.00	4.69
M (3)	4.00	4.00	4.33	4.33	4.17
L (1)	4.50	4.00	4.25	4.75	4.38
K (2)	4.50	4.00	4.44	4.69	4.41

5.4.3 Phase 2b “Script”

In Phase 2b of this study, cave tours were altered with guides using a script created from the pamphlet as well as questions on the assessment instrument utilized in this study, to deliver content. Age distribution of this Phase and their resulting score breakdown is shown in Table 5.10. Results from this phase did have higher scores than the Phase 1, but not as high as Phase 2a. These results are summarized in Table 5.11, showing differences between means, T value, and probability values. Groups during this phase of study were of similar demographics as the prior phases, with roughly the same number of sizes; however, from the survey section of the assessments, more visitors, from 0 in Phases 1 and 2a to four in Phase 2b requested that the guide not sound “rehearsed” and allow for more casual talking with occasional jokes.

Table 5.10. Phase 2a summary of respondent scores by variables. Guide, tour size, number of respondents shown with corresponding average percent increase between pre and post assessments.

Guide - Size of group (# of respondents)	Average of %increase	Guide - Size of group (# of respondents)	Average of %increase
J		M	
21-39 (14)	106.83%	11-20 (4)	620%
K		W	
21-39 (3)	358.34%	21-39 (4)	172.86%
L			
11-20 (5)	470%		

Table 5.11. ANOVA results for respondent only score analysis, showing score comparisons.

COMPARISON	DIFF OF MEANS	MEANS	T	P
POST 2A VS. POST 1	1.164	3.445 / 2.281	3.971	0.002
POST 2A VS. POST 2B	0.803	3.445 / 3.517	2.739	0.103
POST 2B VS. POST 1	0.361	3.517 / 2.281	1.232	1.000

5.4.4 Summary of Results

From the results of the assessments, it was found that the largest contributing factor to enhancing the learning provided on guided show caves tours is extra interpretive material, in this case, in the form of the walk-along brochure. While providing the guides with scripts to follow can also slightly increase assessment scores, it is not an effective technique given the established method of training and visitor satisfaction with the guide. Overall, a pamphlet increased scores significantly over a script, or nothing, while a script did not significantly improve scores over nothing.

These results indicate that educational outcomes on guided show cave tours can be improved with the use of mobile eye-tracking technology. By definitively locating areas visitors are interested in, locating areas where visitors are losing interest in the guide speaking, and how the lighting itself impacts the visitors engagement with the tour, the tour can be constructed or modified to maximize learning. The inclusion of extra interpretive material is imperative to visitor learning and can easily be created with the use of mobile eye-tracking technology. Table 5.12 shows the score comparisons for all phases. Table 5.13 shows summary statistics for all participant groups and all phases of study. Figure 5.17 shows the scores for all phases for each guide in a box and whisker graph, which shows the minimum and maximum, as well as the average scores.

Table 5.12. ANOVA test results for respondent only score analysis, showing score comparisons between all phases.

COMPARISON	DIFF OF MEANS	T	P
POST 2A vs. POST 1	1.164	3.971	0.002
POST 2A vs. POST 2B	0.803	2.739	0.103
POST 2B vs. POST 1	0.361	1.232	1.000
PRE 2B vs. PRE 2A	0.548	1.870	0.951
PRE 2B vs. PRE 1	0.0803	0.274	1.000
PRE 1 vs. PRE 2A	0.468	1.596	1.000

Table 5.13. Summary Statistics for all groups and phases of study.

	Mean		STD Dev		SEM	
	<i>Assessment</i>	EP	<i>Assessment</i>	EP	<i>Assessment</i>	EP
Pre1	<i>1.73</i>	-	<i>1.36</i>	-	<i>0.24</i>	-
Post 1	2.38	1.94	<i>1.36</i>	1.67	<i>0.24</i>	0.63
Pre2a	<i>1.25</i>	-	<i>1.38</i>	-	<i>0.24</i>	-
Post2a	<i>3.52</i>	3.68	<i>1.26</i>	1.59	<i>0.22</i>	0.59
Pre2b	<i>1.81</i>	-	<i>1.26</i>	-	<i>0.22</i>	-
Post2b	<i>2.70</i>	3.13	<i>0.90</i>	1.08	<i>0.16</i>	0.41

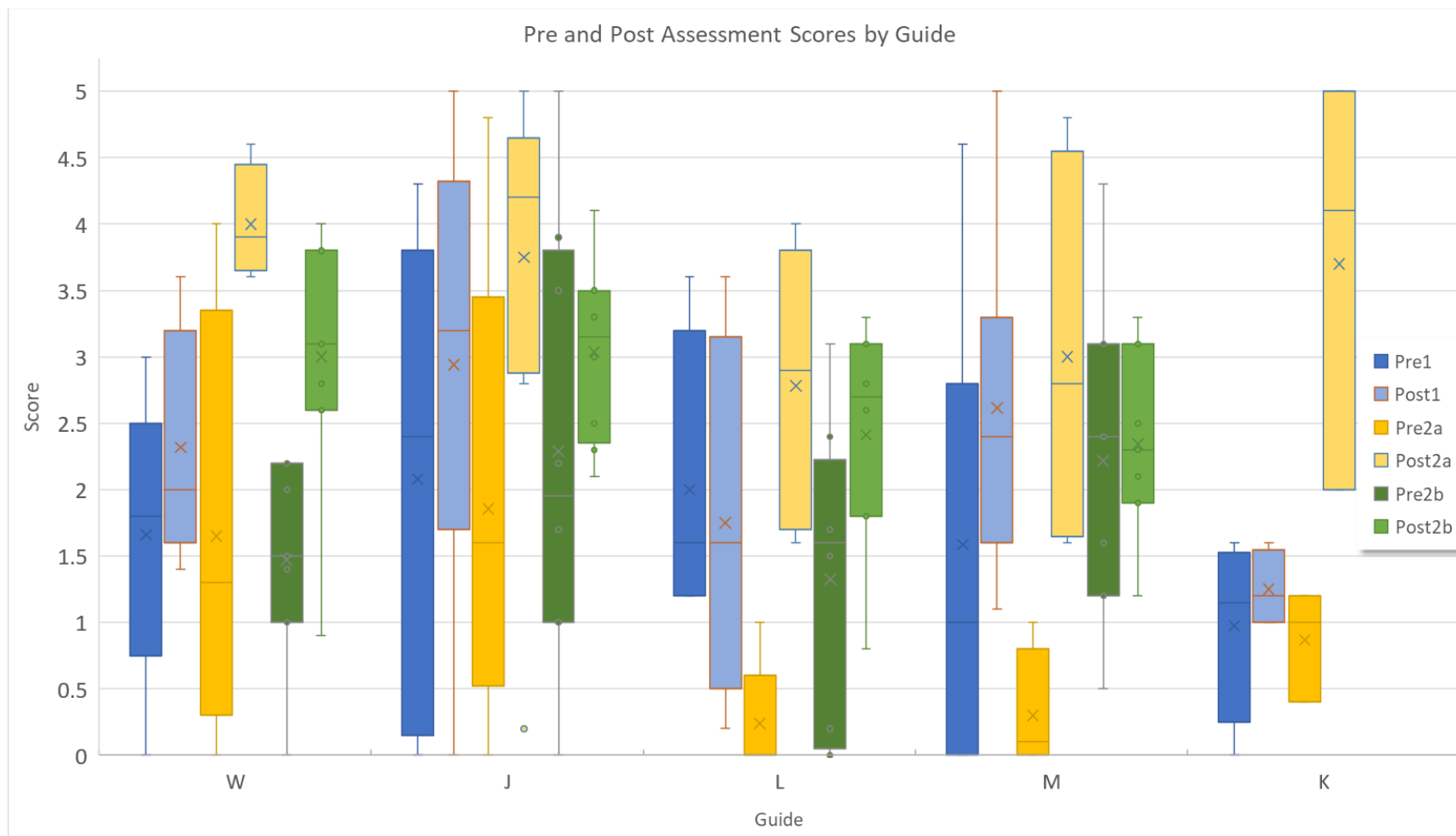


Figure 5.17. Box and Whisker graph displaying scores from each pre and post assessment for each phase by guide. (Created by author).

5.5 Factors Influencing Learning Outcomes

5.5.1 Group Size/Demographics

For Phase 1 of this study, it was noted that participants in larger groups did not perform as well on the assessments as participants in smaller groups. Guide L only led four tours to groups with a larger sizes, while Guide J led ten tours with mostly smaller sized tours. Of the demographics analyzed, tour size had the largest impact on assessment scores. During the 30 tours studied, five had more than 40 participants, 15 had between 21 and 39 visitors, eight had between 11 and 20 visitors, and only two had between 0 and 10 visitors. Tour demographics, such as gender, age, and education levels, etc., were analyzed with none having a statistically significant impact on outcomes assessment scores. Tour sizes over 40 consistently produced lower scores and more negative survey responses about their experience. During the eye-tracking trials, throughout both phases of study, there were several times when visitors were not allotted enough time to observe locations, so they instead resorted to snapping a picture on their phones (Figure 5.18). On these tours, when the guides moved quickly through an area, lower scores resulted.

Visitors in the back of tour groups could not always hear the guide. There were several instances in the Lake Room, when the guide would stand at the far end of the path in the very front of the group, when eye-tracking participants were located towards the back of these large groups. Eye-tracking participants (or nearby visitors) were heard saying they could not hear the guide clearly. While it is impossible to know where survey participants were standing at these stops, we can assume if the eye-tracking participants were unable to hear, anyone else in the back of the group would be unable as well, which would lead to lower scores on questions relating to that stop.

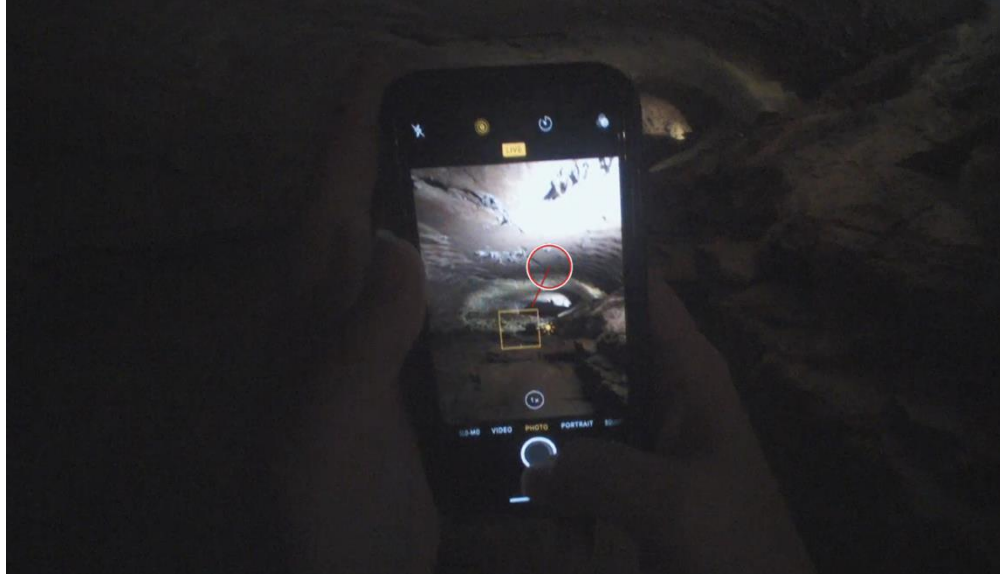


Figure 5.18. Eye-tracking participant takes photo of Cascade Avenue when guide moves too quickly through the area. (Imaged captured by author from eye-tracking recording).

From these data, it was determined that the optimal tour size for this site, Cascade Cave, seems to be between 15 and 40 visitors, while smaller groups (0 -15 participants) still achieved high scores, the guides all indicated they would feel having consistently small sized groups would negatively impact their tours, due to moving quicker through the cave and having to know more information to fill in time. Along with group sizes, the tour guide must consider the optimal locations in the cave to address the group.

5.5.2 Motivation for Visiting

Survey data from the Phase 2a data set also revealed that when visitors indicated a desire to learn more about the cave or the karst environments as compared to visiting the cave purely for entertainment, there was a statistically significant difference in performance on the assessments than other participants from any phase. Figure 5.19 shows the scores of participants who indicated “want to learn” as a reason for visiting for the three different phases, with a noticeable increase throughout the phases. These results

indicate that providing this extra method for learning is a useful tool for visitors there to learn particularly when there is not significant prior knowledge especially. These results may also suggest that if a visitor is only interested in an entertaining experience, they may be impossible to educate properly.

Visitor motivation for visiting the park was the other main influencer in learning outcomes. When a visitor indicated the desire to learn more, they performed markedly better than visitors who were motivated by other reasons, even when participants visiting did not intend to learn (as indicated by the post survey questions), participants still achieved some knowledge of the caves and karst landscapes. This is especially true when these visitors were provided with an alternative method for learning (e.g. the pamphlet).

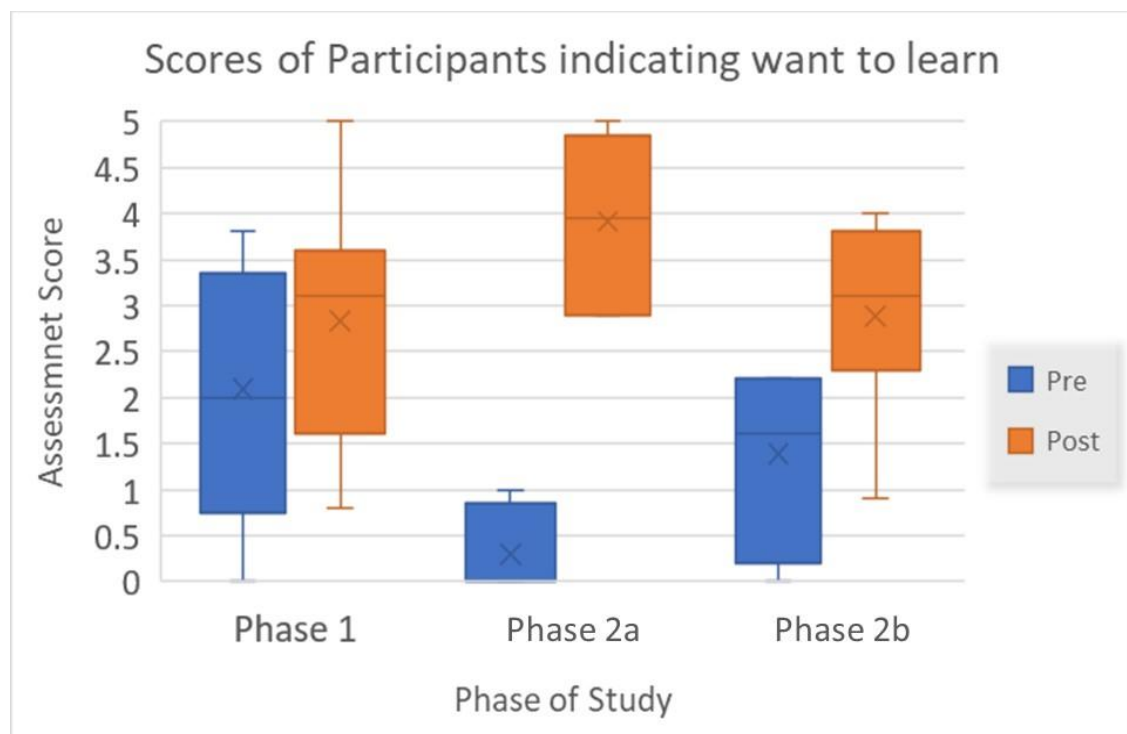


Figure 5.19. Scores of participants who indicated 'want to learn' as a reason for visiting for the three different phases. (Created by author)

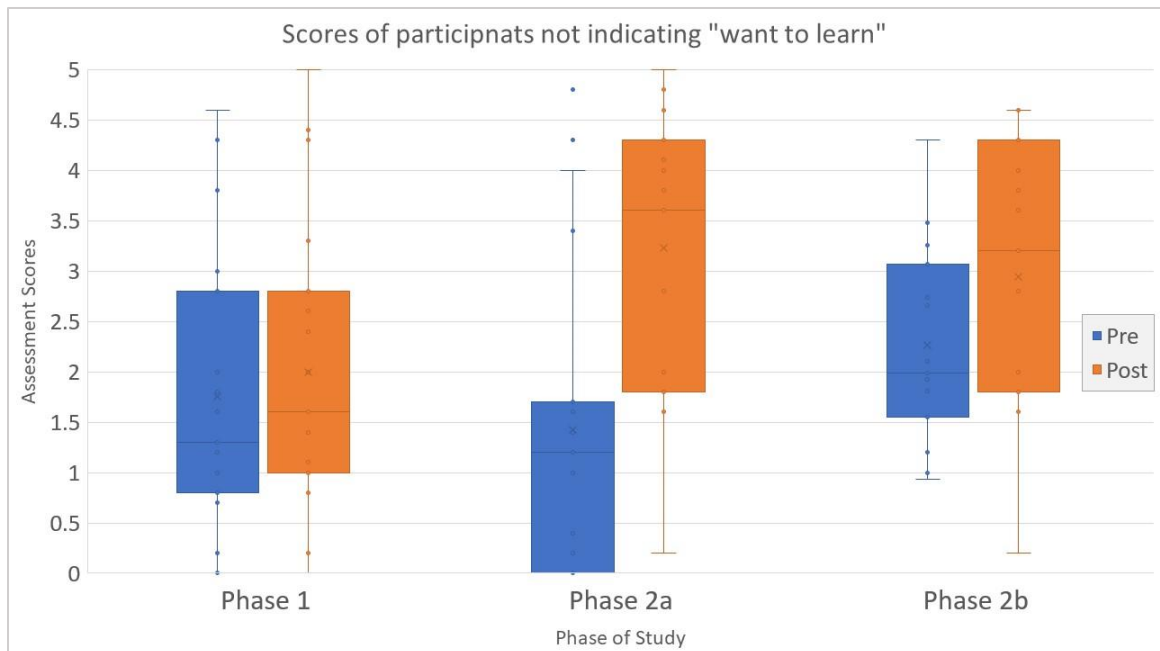


Figure 5.20. Scores of participants who did indicate 'want to learn' as a reason for visiting for the three different phases. (Created by author)

Chapter 6: Conclusions and Future Research

6.1 Conclusions

The purpose of this research was to determine the usefulness of mobile eye-tracking technology and how it can help improve education on a guided show cave tour.

This research aimed to answer the following questions:

1. How can eye-tracking technology be utilized to improve the educational quality of guided show cave tours?
 - Can eye-tracking technology be used to identify common interest points along show cave tour routes?
 - If so, can identifying common points of interest on a cave tour enhance the understanding of the information provided to cave visitors?
2. How can information supplementary to guided tour content, such as ‘follow-along’ brochures, be created using eye-tracking data?

By using a mixed methods approach, using mobile eye-tracking technology and pre-and post-assessments to assess visitor behavior and learning outcomes. While this study did yield interesting results, it should only be considered a preliminary study of the uses of mobile eye-tracking technology for show cave development. Due to technical difficulties experienced with the glasses, the researcher was unable to conduct the study at multiple sites. Gaze samples nonetheless allowed for quantitative analysis of visitor observations and behaviors inside a single show cave in the form of heat maps and gaze plots, while pre- and post-assessments allowed for a way to quantify change in visitor knowledge from participation in the show cave tour.

The use of the mobile eye-tracking glasses (audio and video recordings) and visitor remarks allowed for major changes with the infrastructure of the cave tour; altering the lighting of the entire cave tour route to better address the safety of visitors. Without these data, it would not have been definitively known the extent to which safety

played a role in visitor learning outcomes; visitors need to feel a certain amount of safety to remain engaged in the learning taking place throughout the cave tour. These glasses also provided further evidence of ideal stopping points, specifically for tours with larger groups. A stated goal of this study was to find possible new stops within the cave tour for interpretation. While this may be possible to do, it was beyond the scope of this project due to the cave being studied.

The methodology tested with this study proved useful at Carter Caves State Resort Park, but other locations with varying interpretive resources may yield different results. Nonetheless, mobile eye-tracking was found to be incredibly useful at the established show cave site studied in this research in answering the research questions of this study. With the mobile eye-tracking glasses, common interest points were able to be determined, and by identifying these points, educational material was able to be created that provided supplemental educational material for cave visitors, in the form of a ‘walk-along’ educational packet about the local karst area. Without the use of mobile eye-tracking technology, it would not have been possible to definitively identify areas that visitors were most frequently observing. The additional bonus of the technology recording all audio from the tour proved useful when creating the pamphlet; it was possible to determine what information guides may not address as frequently. As a result, the educational quality of guided show caves tours at Carter Caves State Resort Park was improved thanks to the use of mobile eye-tracking technology.

Designing a cave tour that visitors can be entertained in, while being educated is imperative to learning about these karst environments. Show caves are among the best ways to mass educate about the unique qualities of a karst landscape. The use of mobile

eye-tracking technology allowed for the researcher to design a tour that visitors were entertained by identifying common points of interest and other areas that often caught visitor attention. Through the use of audio recordings and post assessment data, researchers were also able to determine how the tour guides themselves impacted the overall educational and entertainment values of the cave tour; guides need a level of informality with visitors while still remaining in a teaching role.

6.2 Future Research

Future research could involve the use of mobile eye-tracking technology prior to cave tour development to locate the ideal trail, lighting positions, and the educational outcomes of visitors to these cave sites. These were proven to be factors that impact visitor behavior and learning at Carter Caves. By having participants walk through the cave prior to development, common points of interest can be determined and likely will save time and money in the long run and have high visitor approval from the beginning.

From this study, it was ultimately found that there is a connection to how visitors learn based on the guides (in terms of their years of experience and the delivery/content knowledge). Studying this in more detail would likely lead to a better method of training guides. For instance, Guide W, while having only worked at the park for two seasons, was able to achieve excellent education results with visitors, possibly due to his experience as a science teacher for decades prior to leading cave tours. Meanwhile, Guide L, a recent high-school graduate and first year employee, produces lower scores without the help of the informational packet or a script to follow. Results also indicate that in locations without other resources for visitor education providing some form of additional material (the walk-along pamphlet) was crucial to visitor learning. Future studies could

reveal more effective methods to aid visitor learning and help sites that are developing
provide high quality education to visitors.

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APPENDIX A:

Tour outcome assessment

Please give us your feedback concerning your tour experience by completing the following voluntary assessment as accurately and honestly as possible and return once completed.

If you don't know the answer or have an educated guess to a question, please leave it blank.

- 1) Please define the word **karst** or describe a **karst landscape**.
- 2) How can humans impact karst groundwater resources in terms of quality of the water and amount of water?
- 3) Please indicate whether the following statements are true or false.

4)

	True	False	Don't know
a) Limestone rock acts a good filter			
b) Water can rapidly travel from the surface to subsurface in karst areas			
c) Caves serve as a pathway for water to travel through karst terrains			
d) Cutting down trees is good for karst			

- 5) Living organisms that are beneficial to humans are found caves? True or False
- 6) Name one-way pollution on the surface can make its way underground in karst areas?
- 7) Generally speaking, how large might the area above ground be that affects a cave?
Please circle one.
 - a) only the land directly above the cave
 - b) the entire state the cave is located in
 - c) the land above and nearby the cave
 - d) no land above the ground

8) What is your Age? 18-30 31-40 41-50 51-60 61-70 71-80 81-90 > 90

9) What is your Highest Level of Education?

Nursery school to 5th grade

6th to 8th grade

9th to 11th grade

High school or equivalent

Some college, no degree

Associate's degree

Bachelor's _____ Graduate degree _____

10) What is your primary state/country of residence?

11) Which of the following best describes your reason for visiting this show cave today?

Check all that apply.

- ☐ Purely entertainment
- ☐ Really wanted to learn about caves/karst
- ☐ Other_____
- ☐ Saw a sign, thought interesting

Wanted to see a cave firsthand

12) Had you heard about karst landscapes before today? YES or NO

If you answered, yes, please indicate where you heard about karst prior to today by checking all that apply.

- ☐ Televised news report
- ☐ Public workshop
- ☐ Work related
- ☐ Newspaper
- ☐ Friend or family
- ☐ Child
- ☐ Classroom
- ☐ Show cave or park
- ☐ Other_____

13) On a scale of 1 to 5 (5 representing the most satisfaction) please rate your overall satisfaction with your tour today.

1 2 3 4 5

14) On a scale of 1 to 5 (5 representing the greatest) how would you rate your tour in terms of education?

1 2 3 4 5

15) On a scale of 1 to 5 (5 representing the greatest) how would you rate your tour in terms of enjoyment?

1 2 3 4 5

16) On a scale of 1 to 5 (5 representing the greatest) how would you rate the quality of your tour guide?

1 2 3 4 5

17) What can be changed to make the tour more beneficial/interesting to you?

18) Had you taken a show cave or spring tour before today? YES or NO
If yes, what facilities have you visited?

19) Were your tours at other facilities more or less educational than your tour today?

APPENDIX B:

Informational Pamphlet given to visitors during phase 2a.

Pollution in Karst Landscapes

Because of the nature of karst landscapes, (the interconnected networks of sinkholes, springs, caves and underground rivers/aquifers), after every rainfall, trash and chemicals on the surface can easily (and rapidly) make their way through these natural or man-made openings and into the groundwater. These pollutants can travel incredibly long distances in the underground rivers. Underground rivers and surface rivers often look very similar!

There are two main reasons why karst landscapes are vulnerable to groundwater pollution:

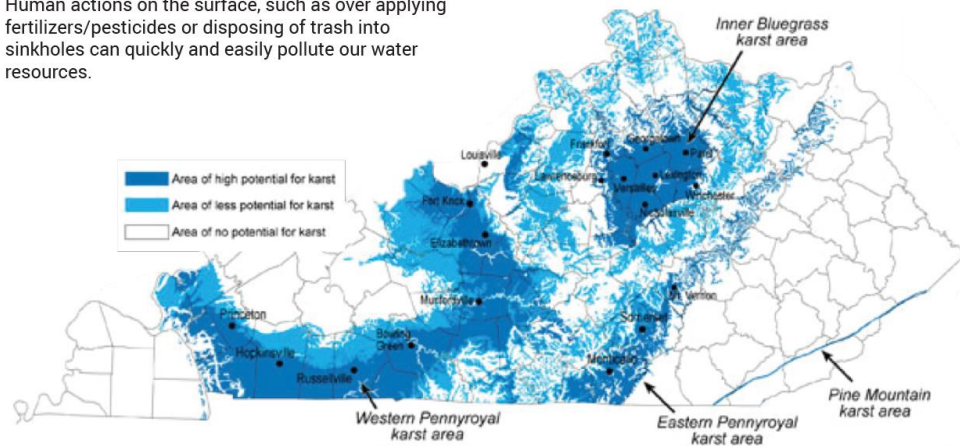
1. The surface and subsurface are more connected in karst areas than most other landscapes.
2. The bedrock that karst forms in (often limestone) does not filter pollution from water.

Human actions on the surface, such as over applying fertilizers/pesticides or disposing of trash into sinkholes can quickly and easily pollute our water resources.

Groundwater may be out of sight temporarily. But because we live on a karst landscape, it may eventually resurface with all of the pollution it has been carrying. This pollution could be trash, debris, or even harmful chemicals from agricultural fields, home lawns, pet waste, sediment, and urban streets and parking lots.

Why Does This Matter?

- Karst aquifers supply 20-25% of the world's population with fresh drinking water.
- Karst landscapes cover about 12% of the world's ice-free land surface, in areas where more than 25% of the world's population live.
- Almost 50% of Kentucky is made up of this landscape, with at least 1.8 million people receiving drinking water from within a karst system.



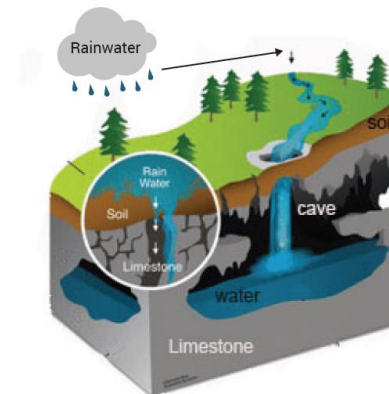
Karst Landscapes

Under your feet exists a world of darkness, where caverns are formed by flowing water, to create a distinctive landscape known as karst.

Karst landscapes form in areas where rock that is able to dissolve is found. The most common rock that karst landscapes form in is limestone.

Karst areas form slowly over thousands of years as slightly acidic water (known as carbonic acid) seeps into the ground and dissolves the soluble bedrock underground. Carbonic acid forms when water (H₂O) mixes with carbon dioxide (CO₂) that is naturally occurring in the atmosphere and soil.

Eventually, as the soluble bedrock dissolves away through the dissolution process, the characteristic features of a karst landscape, such as networks of sinkholes, springs, caves, underground rivers and aquifers, are formed.



Cascade Caves at Carter Caves

Carter Caves may be a protected area with little risk of major contamination that would impact the local population, but it is an ideal location to educate on these delicate karst landscapes that surround us!

While sometimes hard to see with the overgrowth in the woods, notice the small depressions off the sides of the trail. These are sinkholes! These serve as nearly direct channels into the cave system, meaning anything that falls in to them, could contaminate the cave, and the groundwater within.



The Ballroom

Once inside the cave, you see how water has shaped these passages over millions of years, this first room, known as the Ballroom, has a rich history, both in geologic and human terms! Once used as a dance hall, barn, and likely a speakeasy, this passage is phreatic in origin, meaning it was carved completely within the water table.



Bats in the Caves

Throughout this room you will often see many bats hanging from the various nooks and ridges along the ceiling. Carter Caves is home to many species of bats, all of which play an important role in the ecosystem of the park. Bats are a large predator for flying insects (like mosquito's) and are a major pollinator.



A group of bats hanging out at the top of Cascade Caves.

The Lake Room

The Lake Room is a great location to see how water flows through these landscapes. This underground creek looks just like a surface creek, even further into the cave system beyond our sight.



The Metal Pole

One of the more curious sights in Cascade Cave, a large metal pole intrudes on the scenery in North Cave.

While folk stories passed down from cave guides say this was a sewage pipe, it was actually just used to pump water from the creek into the old Cascade Cave Hotel, located on the land above. But it is a good visual aid to see potential effects. Had it been a sewage pipe, it would have pumped straight into the creek, which was and still is used for drinking water.

This may seem like an unlikely occurrence, but this was a common solution to unwanted sewage in the early 1900s throughout areas of Kentucky.



Definitions

Soluble – able to dissolve in water

Bedrock – solid rock underneath the soil

Water table – a level beneath the surface of the earth where pore spaces become full of water

Watershed – The surface area of land that contributes to a stream

Discharge – the removal of water from an aquifer or other water body

Recharge – the addition of water to an aquifer or other water body

Porosity – The volume of open space in a rock, soil or sediment

Potable water – Water that is drinkable

Infiltration – The movement of water from surface into the ground

Spring – a geographic location where groundwater naturally discharges onto the surface or into a body of water

Runoff – water moving over the land surface